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Observer Coverage of the Atlantic Canadian Swordfish and Other Tuna Longline Fishery: An Assessment of Current Practices and Alternative Methods

Présence d'observateurs dans la pêche à la palangre de l'espadon et des autres thonidés du Canada atlantique : évaluation des pratiques actuelles et autres méthodes

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ABSTRACT

The sampling of the Atlantic Canadian longline fishery by the Canadian Fisheries Observer Program is reviewed to determine if the sampling is representative of the aerial and temporal extent of the fleet's fishing, the range in fishing capacity or power of its vessels, and the intensity of fishing with respect to time, area, and vessel characteristics. The precision of ratios used to scale bycatch to the whole fleet is evaluated for the existing sampling design with a view to recommending practical alternative sampling and stratification schemes and optimal levels of observer coverage for seven study species (bluefin tuna, porbeagle shark, shortfin mako, blue shark, leather back turtle, and loggerhead turtle). Further, alternative ways of scaling the observed bycatch to the entire fishery are compared and alternative methodologies are considered to see if there is a need for case specific estimation techniques.

RÉSUMÉ

Les échantillons de pêche à la palangre dans le Canada atlantique, prélevés dans le cadre du Programme des observateurs des pêches du Canada, sont examinés pour déterminer si les échantillons sont représentatifs de l'étendue aérienne et temporelle de la pêche de la flottille, de l'éventail de capacité de pêche ou de la puissance des navires et l'intensité de la pêche relativement aux périodes, aux zones et aux caractéristiques des navires. La précision des rapports utilisés pour pondérer les prises accessoires à l'échelle de toute la flottille est évaluée pour la conception d'échantillonnage existante, en vue de recommander d'autres échantillons pratiques, des programmes de stratification et des niveaux optimaux de présence d'observateurs pour sept espèces étudiées (thon rouge, requin-taupe commun, requin-taupe bleu, requin bleu, tortue luth et caouane). De plus, d'autres moyens de pondération des prises accessoires observées dans l'ensemble de la pêche sont comparés et d'autres méthodes sont envisagées pour voir si des techniques d'estimation particulières sont nécessaires.

INTRODUCTION

The Atlantic Canadian swordfish and other tunas longline fishery incidentally catches species that must be discarded. Under an Ecosystem Approach to Fisheries Management it is necessary to be able to control the incidental mortality of non-harvested species and the discard mortality of undersized harvested species. Before one can affect controls, however, accurate and precise estimates of the discarded amounts must be available. The purpose of the work presented here, then, is to review the sampling methodology on which current estimates of discard amounts are based with a view to determining how the degree of observer coverage affects the precision of the estimates. Factors that affect the accuracy of estimates, such as bias in the sampling, are also considered. Lastly, how the choice of a scaling variable affects the estimated discard amount is investigated.

A LITTLE HISTORY

The history of swordfish and other tuna harvesting dates back to the mid-1800s. This work, however, only pretends to describe the activity of the fishery in the past decade from 2002 to 2010. In order that one might better understand this recent history and how it bears on the data, relevant excerpts from the overview of the fishery found in the Canadian Atlantic Swordfish and Other Tunas 2004-2006 Integrated Management Plan (DFO 2004) are presented.

Swordfish

The Atlantic swordfish fishery began commercially in the late 1880s as harpoon sailing vessels fished swordfish throughout Atlantic Canada and eventually expanded their fishery along the annual migration patterns of the eastern seaboard of North America.

In 1988, minimum sizes were put into place. This resulted in Canada reducing its quota and in the introduction of domestic measures to limit the harvesting of undersized swordfish. The first national allocations to International Commission for the Conservation of Atlantic Tunas (ICCAT) Contracting Parties were made for 1995. Between 1995 and 2000, reductions in the Canadian quota resulted in the need for significant changes to our swordfish management strategy. Significant changes in management strategy were implemented under the 2000-2002 Swordfish Plan (DFO 2004) and hinged on fleet allocations to each of the harpoon and swordfish longline fleets. In addition, the swordfish longline fishery implemented a number of measures under their Conservation Harvesting Plan designed to reorient effort toward other tunas within their fleet allocation. In 2002, these management measures were further refined with the introduction of Individual Transfer Quotas (ITQs) to the longline fleet on a trial basis, and permanently in 2003. Starting in 2003, ICCAT approved a substantial increase to the Total Allowable Catch (TAC) of north Atlantic swordfish, to 14,000t from 10,400t the previous year, including discards. This increase is owing to improved stock status under the 10-year recovery plan. The most recent stock assessment (ICCAT 2009) has indicated the stock is rebuilt by ICCAT standards.

Other Tunas

Bigeye, yellowfin and albacore tuna fishing throughout the east coast of Canada can be traced back to the 1860s. Starting in 1987, Canada has been supporting a strategy to develop a fishery for these species.

In 1987, two exploratory offshore tuna licences were issued in an attempt to develop a fishery for bigeye, yellowfin and albacore tunas. In 1991, one of these exploratory licences was made permanent after having met the requirements for Canadianization of a vessel in the fishery. This licence operates today and carries with it a bycatch allocation for swordfish and bluefin. The bycatch allocations always remained subject to review and were reduced over the years to their current levels of 5t for swordfish and 20t for bluefin. The licence is also subject to catch composition requirements to ensure the majority of the catch is tuna species other than bluefin tuna.

In 1995, swordfish longline licence holders were issued licences authorizing them to direct for bigeye, yellowfin and albacore tunas. Prior to 1995, persons fishing under the authority of a licence for swordfish with a longline could retain tuna other than bluefin, which was caught incidentally. There are presently 77 swordfish licence holders eligible to direct for other tunas.

Bluefin tuna licence holders using tended line or rod and reel, also are authorized to catch and retain bigeye, yellowfin and albacore tunas caught incidentally under the authority of their bluefin tuna licence conditions and providing there is bluefin quota available to the sector fleet, and a vessel meets the minimum tag requirements. Only those fishing bluefin tuna on the Scotian Shelf (except in 4Wd) and Grand Banks are authorized to retain other tunas. There are 774 bluefin tuna licences throughout Atlantic Canada and Québec.

There are no other tuna quotas allocated to Canada. However, Canada is currently limiting the effort on species such as bigeye tuna and albacore tuna through the use of licences.

Participants

Entry to the swordfish fishery, regardless of fleet sector, is limited to the current licences and has been since 1992. Licences have been fixed at this number, but may be reissued, within certain policy restrictions, from one fisher to another.

In recent years, the Department of Fisheries and Oceans (DFO) has intervened in the transfer process to obtain both harpoon and longline licences for subsequent transfer to Aboriginal persons and communities under the Department's Aboriginal Fisheries Strategy. These transfers do not result in an increase in the overall capacity within the fishery.

Longline Licences

There are a total of 77 pelagic longline licences, of which 75 are currently based in the DFO Maritimes Region. The remaining licences are held in the DFO Newfoundland and Labrador Region. A unique offshore tuna licence, based in the Maritimes Region, is also authorized to operate a longline fishing operation Atlantic-wide. The pelagic longline licences are transferable Atlantic-wide, and the other tunas licences are non-separable from the swordfish longline licences. All but 8 of the 77 vessels licensed to fish swordfish and other tunas are <65' in length; the remaining eight are between 65' and 100' in length. The offshore tuna licence also operates a vessel in the 65' 100' range. Principle ports of landing in the Atlantic Region include Shelburne, Sambro, Wood's Harbour and Clark's Harbour in Nova Scotia, and St. John's and Fermeuse in Newfoundland and Labrador.

Only 40 of the total 77 licences were active in the 2003 fishery. This is down from 63 active vessels in 2001, the year prior to the introduction of ITQs. Over the past few years, few Newfoundland-licensed vessels have participated in the pelagic fishery due to involvement in other fisheries (i.e., snowcrab and shrimp). As well, the introduction of an ITQ management approach since 2002 has allowed some long overdue fleet rationalization to occur. Pelagic longline vessels are also licensed to fish with harpoon gear, but since 2000, any landings by harpoon gear are attributed to the longline quota.

All longline licence holders in 2003 were represented by the Nova Scotia Swordfishermen's Association (NSSA), which is based in Shelburne, Nova Scotia, with the exception of the offshore tuna longline licence, which is a unique licence and is represented by its owner/managers directly.

Location and Timeframe of Fishery

The fishery follows the seasonal migration of the swordfish through Canadian waters, in accordance with the limitations of the gear types used, weather, and the availability of quota. The Canadian large pelagic longline fisheries which direct for, or incidentally catch, swordfish currently operate from April through December, though the season can extend year round subject to quota availability, but to date, vessels capable of fishing the winter season have focused on other fisheries in the January to March period. Prior to the introduction of ITQs, the swordfish fishing season was concentrated primarily in the summer months.

The Canadian large pelagic longline fishery extends from Georges Bank south of Nova Scotia to beyond the Flemish Cap east of Newfoundland when swordfish, the main species targeted, migrate into and adjacent to the Canadian Exclusive Economic Zone (EEZ). Longline fishing effort generally progresses from west to east and back again and from offshore to inshore along the edge of the continental shelf following swordfish movements associated with seasonal warming trends of surface water temperature, and a northward movement of the edge of the Gulf Stream. Swordfish migrate into the Canadian EEZ during summer and fall to feed in the productive waters of the continental shelf slope and shelf basins, areas where water temperatures form a distinct thermocline.

Until recently, the geographic distribution of the pelagic longline fishery tended to be quite similar from one year to the next. However, since 1998, there has been an increase in fishing activity east of the Grand Banks (beyond the Canadian EEZ) out to and beyond the Flemish Cap where catch rates have tended to be higher than other areas. This is also an area where fleets from other nations, such as Japan and the US, longline for large pelagic species. This change in the Canadian fishing operations is attributed to a change in strategy, given the good market prices for other tuna species (i.e., bigeye, yellowfin, albacore) and given the decline in swordfish quotas that occurred in the late 1990s.

Time/Area Closures

Time and area closures are management measures that are utilized in this fishery. Closure details and related protocols are described in section 8.5 of the management plan.

METHODOLOGY

DESCRIPTION OF THE DATA

The fishing data for the eastern Canadian pelagic longline fishery is stored in a relational database called the Maritime Fishery Information System (MARFIS), while data from an At-Sea Observer Program (ASOP) that monitor this fishery is kept in the Industry Surveys Database (ISDB). At a minimum, the ISDB should be an exact subset of the MARFIS data on which it is based with conformity in terminology and structure and easy linking through common identifiers. In truth, although the databases have information in common, the lack of common identifiers, structure and terminology requires having specialized knowledge to extract data from each database. An important consequence of this arrangement is that calculations throughout this report, for corresponding areas, seasons and/or years in each database, are performed without the benefit of match-merging the data based on common elements like trip number, vessel number or date, etc.

In each database, the component that is the swordfish and other tuna longline fishery was defined differently. The definition for MARFIS requires that one specify licence types 251, 257 and 259 (swordfish, tuna restricted and tuna unspecified, respectively) with gear 51 (pelagic longline) and effort amount greater than 10 (effort unit is hooks). An examination of the sets related to effort amounts less than 11 indicated that the fishing activity resembled a tended line fishery and consequently should not be part of pelagic longline calculations.

In the ISDB, it was important to specify gears 50 and 52 (longline (LL) unspecified, LL drift) and trip codes 72 and 73 (swordfish, swordfish plus tuna).

Both databases were able to provide data from 2001 to 2010; however, the 2001 data in MARFIS does not properly identify the trip number in 2001. Consequently, the analysis was restricted to years 2002 to 2010.

The key species used in the analysis are shown in the table below along with the species number assigned to it in both the MARFIS and the ISDB. These species numbers are frequently used in the figures. It is important to note that there is no distinction between short fin and long fin mako sharks in the MARFIS. Therefore, when long fin mako shark are caught in a longline set, the MARFIS recorded weight will be higher than that shown in the ISDB. Long fin mako is, however, rarely caught. The MARFIS does include species numbers for the turtles with 970 reserved for leatherback and 969 reserved for sea turtles. These categories are ambiguous and have no data, so they were not used.

Species	MARFIS code	ISDB code
Swordfish	251	72
Bluefin tuna	254	71
Porbeagle shark	369	230
Short fin mako shark	375	238
Blue shark	372	231
Loggerhead turtle	N/A	9436
Leatherback turtle	N/A	9435

For a portion of the analysis, a value for the days spent at sea was required. This was defined as the difference between the landing date and the board date in the ISDB and the difference between the landed date and sailed date in the MARFIS. When sailed date was missing, the sea day calculation was estimated to be the set count plus 2.

DETERMINATION OF COVERAGE

The pelagic longline fleet's minimum level of at-sea observer coverage (except the offshore tuna licence) is 5% of estimated sea days (based on the previous year's actual sea days). Following a proposal for enhanced observer coverage in this fishery, DFO Science Branch provided a document proposing a deployment scheme for observer coverage in this fishery (Appendix I) that would help distribution schemes achieve the specified objectives of a monthly minimum number of trips in each of the three specified areas (East of 60°, West of 60° and the Grand Banks), as well as a minimum 10% trip coverage during months of high intensity fishing (Table 1).

The level actually achieved is determined for each year using sea days, trips and sets. The coverage is evaluated for its representativeness with respect to area fished, the vessels included, the characteristics of vessels in the fishery and the way the coverage tracked the intensity of fishing during each year.

A Chi-square goodness-of-fit test was used to compare the number of sets observed in each year against counts expected under three different hypotheses. The use of sets allowed the unambiguous identification of effort with one of the three areas referenced in Table 1. Identifying a trip to an area where fishing was in multiple areas was more problematic. The observed number of sets was compared with expected counts for each area x month category; expected counts for each month (areas pooled) and expected counts for each area (month pooled). The three areas were 1) East of 60°, 2) West of 60° and 3) the Grand Banks (Figure 1) and month ranged from May to November in each year. For 2002 and 2006, month included April and December, respectively. Structural zeros (i.e., categories with no fishing effort) were removed from the analysis.

The three null hypotheses were as follows:

1. The number of sets observed was a constant percentage of the total fishing in each of the categories (areas and/or months) for a given year. The percentage was taken to be the proportion of sets observed in that year.
2. In each year the number of sets observed followed the recommendations by Science (Table 1).
3. In each year the number of sets observed followed the recommendations by Science (Table 1) for each month, but the sampling in each area varied according to the proportion of fishing that occurred there.

Because of the small expected counts in some cells, p-values were computed by Monte Carlo simulation (Hope, 1968) where the number of replicates was set to 1000. The simulation was done by random sampling from the discrete probability distribution specified by the expected probabilities where the size of each sample was equal to the total number of observed sets. The rank of the Chi-square test statistic from the observed counts relative to the test statistics from the simulated counts provided the p-value.

The Pearson residuals, $(O-E)/\sqrt{E}$, from the goodness-of-fit tests were plotted against the main factors involved in the test. Given that the data for each year was subject to multiple tests, we account for the family-wise error rate using the Šidák test (Šidák, 1967).

RATIO ESTIMATION METHOD

The ratio method is a simple method of estimation that works well under a range of frequency distributions. The ratio method was used to estimate the total discard weight and total discard number of the seven study species (swordfish, bluefin tuna, porbeagle shark, blue shark, short fin mako shark, loggerhead turtle and leatherback turtle). In the ratio method, an auxiliary variable x_i, which is correlated with the observed discard weight or discard number, y_i, is used to estimate the total discard weight or number $\hat{Y}_R$. This required knowledge of X, the total for the auxiliary variable in the entire fishery (Cochran, 1977).

The sample unit was fishing trips and the auxiliary variables tested (x_i) were hooks, sea days, sets, landed weight of the catch and landed weight of swordfish.

The annual ratio estimate of Y, the fishery total of the y_i, is

$$\hat{Y}_R = \frac{y}{x} X$$

where y and x are the sample totals of the y_i and x_i, respectively. This can be rewritten as

$$\hat{Y}_R = \hat{R} X$$

where $\hat{R} = y/x$. The precision of the estimates of the population ratio $\hat{R}$ and the estimate of the population total $\hat{Y}_R$ are reflected by their variance and Coefficient of Variation (CV). These were evaluated for each year-species-auxiliary variable combination. In a simple random sample of size n from a population of size N, the sample estimate of the population variance S^2 is

$$S^2 = \frac{\sum_{i=1}^{n} (y_i - \hat{R} x_i)^2}{n-1}$$

The estimated variance of $\hat{Y}_R$ is then

$$v(\hat{Y}_R) = \frac{N^2 (1-f)}{n} S^2$$

and the estimated variance of $\hat{R}$ is

$$v(\hat{R}) = \frac{(1-f)}{n \overline{X}^2} S^2$$

where $f = n/N$ is the sampling fraction. Confidence intervals for both Y and R can be obtained simply when the sample is large enough so that the normal approximation applies and are

$$\hat{Y}_R \pm z \sqrt{v(\hat{Y}_R)}$$

$$\hat{R} \pm z \sqrt{v(\hat{R})}$$

The coefficient of variation is the same for both $\hat{Y}_R$ and $\hat{R}$ and is represented by

$$cv = \sqrt{\frac{v(\hat{Y}_R)}{Y^2}}$$

The strength of the relationship between the auxiliary variables and the observed weight or discard number was evaluated for each species in each year using

$$r_{xy} = \frac{\sum_{i=1}^{n}(y_i - \bar{y})(x_i - \bar{x})}{\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2 \sum_{i=1}^{n}(x_i - \bar{x})^2}}$$

and approximate 95% confidence intervals were obtained for r_{xy} using Fisher's z-transformation.

It is important to note that while the ISDB differentiates between the discarded and total weight of a species, it only reports the total number. Consequently, the estimated total number of discards for harvest species will be biased upwards. Also, non-harvest species are not generally weighed so the discarded weight is an estimate.

MONTE CARLO ESTIMATES OF PRECISION

The precision of the estimate of the total number of discards, $\hat{Y}$, was determined for the seven study species under different levels of observer coverage using Monte Carlo simulation. Under an assumption of simple random sampling, the total number of discards was estimated by

$$\hat{Y} = N\bar{y} = \frac{N}{n}\sum_{i=1}^{n} y_i$$

where the unbiased estimates of the variance of $\bar{y}$ and $\hat{Y}$ are related by the expression $v(\hat{Y}) = N^2 v(\bar{y})$. Consequently, Monte Carlo estimates of the precision of $\bar{y}$ could easily be converted into estimates of the precision of $\hat{Y}$ given knowledge of *N*. . The simulation algorithm for estimating $\bar{y}$, its standard error, coefficient of variation and bias contained the following steps:

1. Set the observer coverage. The ranged explored was 5% to 100% in 10% increments.
2. Set the number of sets in the fishery (1000 or 2000) and the number of simulations (10,000).
3. For each species, determine the proportion of sets with an occurrence using sets from all years in the time series. Using only the sets with an occurrence, determine the Probability Density Function (PDF) that best fits the data (i.e., has the smallest log-likelihood; fitdistr() from MASS package in R, Venables and Ripley (2002)).
4. Assuming that the estimated PDF for positive sets represents the PDF for the population, sample from it to simulate the catch/bycatch for the specified number of fishing sets (1000 or 2000). Using the proportion of occurrence established for each species (in 3) above), randomly determine which of the simulated sets will be non-zero.
5. Determine $\bar{Y}$, the population mean.
6. Sample with replacement from the population of sets at the prescribed proportion of coverage.
7. Determine $\bar{y}$, the sample mean.
8. Repeat process 10,000 times for each level of observer coverage.
9. Calculate the average $\bar{y}$ and $\bar{Y}$, CV, bias= $(\bar{Y} - \bar{y})/\bar{Y}$, standard deviation and bootstrap t-interval for each species.

So, for example, a species might have 60% occurrence in the sets that were observed and the PDF would be constructed from these data. In a single iteration of the above meta-code, where coverage is set at 10% and the number of sets is 1000, one would draw 1000 times from the PDF and randomly set 400 of these observations to zero and then determine $\bar{Y}$, the population mean for this particular simulation. One would then sample with replacement from this population of sets creating a sample of 100 sets and determine $\bar{y}$ the sample mean. From the 10,000 sample means, one can determine the precision of the estimator at a 10% level of coverage when N=1000.

RESULTS

EVOLVING PATTERNS IN THE FISHERY

Vessel Characteristics

In each year, the pelagic longline fishery was prosecuted by a group of vessels that changed in number (Figure 2). The number of different vessels has been in decline since 2006 from 45 to about 30 vessels in 2010. In each year, the peak in the number of vessels fishing occurred around August or September, with a tendency in the past few years for the peak to occur earlier.

Most of these vessels were from 40 to 45 feet long with one over 100 feet in length (Figure 3). There has been a decline in the number of vessels in the 40 to 45 foot class since 2008. Vessels were most frequently between 0 to 20 gross tonnes. Vessels greater than 20 t have declined in number since 2007 (Figure 4). There has been a shift, beginning in 2006, towards vessels with a break horsepower (hp) of 300 hp from about 150 hp (Figure 5).

Fishing Effort

The fishing effort is reflected by the number of trips, sea days or sets. Figure 6 shows that the number of trips has declined from a peak value of around 260 in 2006 to series lows in 2008 to 2010 of about 160 trips. Since 2006, the effort has shifted to a peak in August from September. The number of sets follows a similar trend with a decline from 1800 in 2006 to the series low in 2010 of 1000 sets (Figure 7). It was less obvious that there was a modal shift in the month of peak fishing; rather the trend recently has been for the fishing to be less focused on the modal month. As with sets, sea days have been in decline since the peak in 2006 (Figure 8). Sea days have dropped from 2400 to 1600 by 2010 with the tendency within the season for the effort to be distributed more evenly across the peak months.

The effort in trips is shown relative to four vessel length classes (Figure 9). The decline in trips was evident in three of the four length classes. Vessels less than 47.5 feet represented the majority of the fishing effort and also had the greatest absolute drop. The distribution of trips by vessel length class and months for pairs of years showed a slight shift in fishing effort from September to August after 2006 for vessels less than 47.5 feet in length (Figure 10). The 47.6 to 57.2 foot length class showed a decline in trips during this period while the remaining length classes appeared more stable across and within years.

The distribution of pelagic longline fishing effort by area is shown for sets (Figure 11), trips (Figure 12) and sea days (Figure 13). Except for minor differences in detail, all three measures of effort describe the same pattern within each of the areas. In the area of the Grand Banks and northward (3KLONM), the effort in sea days has dropped since 2003 from 450 to its lowest value in 2010 of 100. To the west, in 3P4V, the decline is of similar magnitude but only since 2005. West of 3P4V are two areas representing most of the fishing effort, 4W and 4X. Both have shown declines in sea days since 2006 from 1600 to 800 by 2010. The final two areas, 5ZY6DE and ATLIC[1], have shown increases in sea days. Area 5ZY6DE has increased from 250 to 500 sea days from 2002 to 2010 while ATLIC increased from 0 in 2006 to 130 days in 2010.

HISTORICAL COVERAGE

The coverage achieved in any year depended on the measure of effort. Table 2 indicates that prior to 2007, the most optimistic estimates of coverage occurred when using sea days. It is superceded by trip from 2008 to present. Despite these differences, the estimates based on sets, trips and sea days were fairly similar. Figure 14 provides a visual representation of the coverage for each year, using the different definitions of sample unit. The plots of the total sets, sea days and trips sampled relative to 10% of the fleet total indicate that a consistent proportion of the fishing is not being sampled in each year.

Actual Versus Target Coverage Across Areas

The coverage actually achieved (using sets, trips or sea days as the sample unit) is compared with what should have been the coverage given the intensity of fishing. In Figure 15, there is a separate page of five plots for each year showing the relationship between the actual and target coverage using sets as the measure of effort. Figure 16 and Figure 17 observe the same format for trips and sea days, respectively.

These plots have some diagnostic potential as they describe the relationship between the actual and target coverage during each fishing season for each of the measures of effort. A brief description is provided on how a group of plots may be interpreted for one year and then how to describe the main features for each year.

Plot a) for each year shows the distribution of all fishing sets for the year scaled to be a constant proportion of the actual fishing intensity across the whole season from day 0 to day 365. The scaling factor is the coverage achieved in that year. This distribution, shown in black, is represented by a loess smoothed line through the data points while the support for the curve is represented by grey vertical bars. This is called the target coverage while the line in red is the loess smoothed distribution of the observed fishing sets and it is the actual coverage. The length of the steps in this curve reflects the frequency of sampling. Small differences between the optimal and actual coverage suggest that the observer program is tracking the intensity of fishing quite well. Large gaps indicate times when the fishery has been over or under sampled.

Plot b) shows the difference between the optimal and observed coverage in a). When the curve is below the zero reference line the fishery is over sampled. The number of zero crossings indicates how quickly adjustments are made to correct periods of over or under sampling.

Plot c) indicates the actual coverage achieved by the end of the year, as well as the running estimate of the coverage based on the optimal and actual coverage distributions depicted in plot a). Since the target coverage distribution is supposed to be a constant proportion of the fishing intensity on any given day, its running estimate of coverage is always the horizontal line with a value equal to the actual coverage. The running estimate of coverage for the actual coverage distribution fluctuates around the optimum as it approaches the actual coverage achieved by year end. This plot helps to identify time periods where the observer resource has been misallocated.

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[1] The ATLIC area is defined under a condition of licence as being that part of the North Atlantic Ocean, north of 5º00'00"North Latitude and west of 54º30'00"West Longitude.

Plot d) compares the cumulative optimal (black) and actual (red) coverage distributions. The reference lines indicate the day when each curve has accumulated 50% of the observer coverage for the year and the difference in days is indicative of how closely matched the coverage has been since the start of fishing. The cumulative curves may be offset due to periods of no sampling but should be accumulating sets, sea days or trips at the same rate if the actual coverage is matching the target coverage.

The last plot e) separates the periods of over sampling (red) from the periods of under sampling (black). It also shows the cumulative difference between the optimal and actual coverage curves (dashed line). A large amount of separation between periods of over and under sampling is not expected if the coverage properly tracks the actual fishing.

The interpretation of the actual and optimal sampling within each year was similar for each of sets, sea days and trips and, therefore, is described together. Table 2 summarizes the coverage for each of the coverage metrics.

2002: The coverage was in excess of 20% and the observers were present for the whole season. The tails of the season were over sampled and there was slight over sampling of the peak fishing yet the discrepancy was not excessive.
2003: Sampling was episodic resulting some unobserved periods. Over sampling occurred in the tails of the season. Episodic sampling appeared to be more common in years where the percent coverage was low.
2004: There was much over sampling at the start of the season and the sampling appeared episodic. Observers were committed too soon.
2005: Although the sampling was episodic the sampling follows the fishery fairly closely.
2006: The sampling appeared to be out of synchrony with the fishing and there were two periods of under sampling.
2007: There were two periods of under sampling.
2008: The start of the season is over sampled and was followed by 2 months of no sampling.
2009: Periods of over sampling alternated with short periods of under sampling resulting in roughly equivalent trends in coverage. There was some under sampling in the fall.
2010: Some of the early season fishing is missed. The sampling was weighted towards the end of the season.

Actual Versus Target Coverage Within Areas

Table 3 and Table 4 show the observed and total trips and the coverage by area and year using trip as the sample unit. The coverage is plotted in Figure 18 for each area (black line) as is the relative importance of each area to the fishery and sampling program. Ideally the red and blue lines should overlap or describe the same trend. When the blue line is above the red line, a disproportionate amount of the sampling was dedicated to that area in that year. The plot shows that there has been a disproportionate level of sampling in area 3KLONM until recently. Area 3P4V had an appropriate level of coverage while 4W and 5ZY6DE were under emphasized occasionally. 4X stood out as an important area for the fishery that was consistently under emphasized by the sampling program.

As above, the optimal sampling distribution was compared with the actual distribution of sampling but within each area (Figure 19). It was informative to view the time course of the sampling in this way rather than just the trend in the annual statistics. The sample unit was trips and the main observations were as follows:

2002: Areas with a small proportion of the total fishing had a disproportionately high level of coverage (3KLONM, 3P4V and 5ZYDE). Sometimes these areas exhibited very seasonal periods of fishing (3P4V). Compared with 4X, 4W was under sampled for most of the year. The spring and summer fishing was under represented.
2003: It appeared more likely that portions of the fishing would be missed when the overall coverage was low and the area was not often visited by the fishery (3KLONM and 3P4V). In areas frequently fished, the result was episodic sampling (4W and 4X).
2004: Due to low overall coverage, episodic sampling was evident in 4W and a lot of the fishing in 4X was missed.
2005: Sampling of 4W was fairly good but the early part of the fishing in 4X was missed and most of the fishing in 5ZY6DE.
2006: Episodic sampling in 4w resulted in portions of the fishing being missed and the low coverage in 4X also resulted in no sampling during some fishing periods.
2007: All of the fishing in 4X before day 240 was missed and episodic sampling in 4W resulted in more missed fishing.
2008: All of the fishing in 4X before day 260 was missed. In 4W an early component of the fishing season was missed but thereafter the sampling was fairly good.
2009: With an increased overall coverage for this year, both 4X and 4W show fairly representative sampling. The tails of the fishing season in 4W was under sampled.
2010: Low coverage for 4X and episodic sampling result in some missed periods of fishing. With double to coverage of 4X, 4W had a more representative view of the fishing. There was missed fishing activity in 5ZY6DE.

Actual Coverage Versus Science Advice

Given that the allocation of observer days to the fishery was subject to recommendations made by DFO Science, it was relevant to determine if the actual allocations matched the advice. In the advice, the fishing was divided into three areas; west and east of 60 degrees longitude and the Grand Banks. The Grand Banks area is comparable to 3KLONM described above while 3P4V is equivalent to the eastern area. 4X, 4W and 5ZY6DE represent the western area.

The majority of the pelagic longline fishing trips occurred in the western area, with the remainder being split equally between the eastern area and the Grand Banks (Figure 20, upper). Since 2002, there has been a steady decrease in fishing trips going out to the Grand Banks, reaching a series low of two trips in 2010. The eastern area has remained between 6 and 29 trips annually, with no net change since 2002. The western area constituted 150 – 230 trips in the early 2000s, but has remained below 143 trips since 2006.

Reported observer coverage of the fishery was at a series high in 2002, when additional funding allowed for greater than 20% combined coverage for the three areas (Figure 20, lower). In subsequent years, coverage of the western area decreased to a minimum of 3.15% in 2004 and has slowly increased back up to 10%. Coverage of the eastern area has varied between 0% and 20%, with no net change since 2004. For the Grand Banks, observer coverage decreased with fishing trips, leading to 0% coverage in 2008 and 2010, when six and two commercial trips went out, respectively.

Using a goodness-of-fit test, the annual observed number of sets by 1) area and month, 2) area aggregated over month and 3) month aggregated over area was compared to expected counts resulting from three alternate null hypotheses (Table 5). The difference between the observed and expected number of sets in the month-area categories was significant for all years under each of the null hypothesis scenarios and indicated no agreement. The Pearson residuals for the tests relating to each null hypothesis are shown in Figure 21, Figure 22 and Figure 23. In these figures, the residuals for area W60 indicate that the observed counts come closest to agreeing with the hypothesis of "*sampling according to science advice with areas weighted by relative fishing effort*" (SAW; Figure 23). Under the hypothesis of "*sampling according to science advice with areas not weighted by relative fishing effort*" (SANW; Figure 22) the residuals for area W60 were large and positive indicating that more sampling had occurred there than one would anticipate if one was simply applying the rules outlined in Table 1. Conversely, in area E60 and the Grand Banks (GB) the opposite was true; namely, that the observed counts best agreed with the hypothesis of SANW which implies that more sampling had occurred in these regions than one would anticipate if one applied the rule of "*sampling in proportion to fishing effort*" (CP) or even SAW.

The difference between the numbers of sets observed in each area aggregated over month and the number of sets expected under the hypothesis of SANW was significant for all years (Table 5). Thus, the sampling in each area did not conform to a plan of equal sampling effort[1]. The Pearson residuals for the tests relating to the SANW hypothesis, shown in Figure 24 plot B, indicate that area W60 always had more observed sets than one would expect if sampling was conducted strictly according to the science advice (i.e., the SANW hypothesis). Areas E60 and GB always had less than the expected number of sets with GB being the closest to expectation. These results do not, however, imply that these two areas were under sampled while the other was over sampled, but only that they did not match the targets specified by the science advice. The tests of the CP hypothesis showed agreement between the observed and expected counts in the areas, in five of the nine years, while there was agreement for three of nine years under the SAW hypothesis. The Pearson residuals from tests under both hypotheses (Figure 24, panels A) and C)) were very similar and when they were large and positive they were associated with areas GB and E60 while high negative values were observed for area W60. Consequently, across all months, sampling appeared to be a constant proportion of the fleet effort in each of the areas[2] with exceptions resulting from occasional over sampling in areas GB and E60 or under sampling of area W60.

The number of sets observed in each month aggregated over area was significantly different than that expected under the hypothesis of SANW for each of the years (Table 5). However, the residual plots (Figure 25) indicated that while the fit was better for certain years under one of the other scenarios (CP or SAW hypothesis), the residuals resulting from SANW varied over a smaller range except for a couple of exceptions. Large residuals and large Chi-square test statistic values were observed for tests subject to the SAW hypothesis. Generally large deviations from expectation occurred when more samples were allocated to the spring and fall months than were available under this sampling scheme. Under the CP hypothesis, deviations from expectation were less extreme and were closest in magnitude to those seen for SANW[3]. Thus across all areas, the sampling frequencies observed for each month seemed to be guided by the scientific protocols but also incorporated real-time adjustments of the sampling to possibly adapt to an unpredicted redistribution of the fleet's effort.

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[1] The prescribed amount of sampling effort assuming fishing in each of months 5 to 11 equaled 15 trips per area at 20% coverage.

[2] Both the CP and SAW hypotheses have a proportional sampling component.

[3] This observation makes sense since the sample scheme developed by DFO Science reflected the changing effort of the fleet over a typical season.

Observer Coverage by Vessel Size

If the composition of the longline catch is affected by vessel size, then the sampling must be structured to include all vessel size classes in proportion to their prevalence. The length composition of the pelagic longline fleet in each year from 2002 to 2010 is shown relative to the length composition of the observed portion (Figure 26). Except for 2009, it appeared that the longer vessels were more frequently sampled than the remainder of the fleet.

When the association between vessel length class and the duration of fishing trips is examined (Figure 27) for the entire fleet and the observed portion, it appeared that, except for the largest length class, the shorter duration trips were under represented in the sample. The percentage of the trips or sea days observed in each vessel length class (Figure 28 and Figure 29) was always greater among the longer vessels for all years except 2009.

Vessels Sampled

The vessels observed should be typical of the variety of vessels active in the fishery. As the fishery adds or drops vessels the sample must likewise adjust. The program should not be sampling from the same vessels each year. Figure 30 show the number of unique vessels sampled in each year from 2002 to 2010 with the corresponding number of unique observed vessels. Since 2007, there was a loss of unique vessels by the fishery; however, the observed number has been stable resulting in a greater proportion of the active vessels observed recently. These trends do not indicate whether the same boats are being observed.

In Figure 31, the new entrants to the fishery and the observed subset are shown being in 2002. In each year, the number of new vessels is added to the number previously observed. Given that the two trend lines are roughly parallel, it appears that rate of acquiring new vessels in the fishery is matched by the observer program.

RATIO ESTIMATES

The population ratio of discarded weight and number to various effort-based and landed-weight-based auxiliary variables was estimated by the observed ratios of these variables. This ratio was used to estimate the total discarded weight and number given that the total for the auxiliary variable in the ratio is known. The correlation between the variables in the numerator and denominator of the ratio needs to be strong in order for there to be a benefit to using the ratio method over the expansion method. An additional condition that must be satisfied for the ratio method to have a benefit over simple expansion is that the variables in the ratio have a strong linear relationship that passes through the origin. This particular requirement was not tested.

In general, it was observed that there was a year effect in terms of the precision of the ratio estimates regardless of the species examined (Figure 32). The ratio estimate varied from year to year and the precision of the estimate did not appear to be related to the size of the sample. The correlation between the variables in the ratio was poor (<0.5) for the turtles and bluefin tuna. The correlations were good for swordfish and decent for porbeagle and blue sharks. For leatherback turtles and bluefin tuna, effort-based auxiliary variables provided the best correlation, whereas for swordfish it was the landed-weight-based variables.

The product of the estimated population ratio and the total of the auxiliary variable in the population provided the estimate of the population total. The estimated total weight and number discarded is shown for each of the species using each of the auxiliary variables described above (Figure 33). As for the estimate of the ratio, there is a year effect for the estimate of the total and its confidence bounds for all species. The turtles exhibited CVs above 0.3 for almost all auxiliary variables and years. This tended to be the case for bluefin tuna as well except in 2002 and 2010. For all three species, the effort-based variables tended to provide the lowest CVs.

The effort-based variables also provided the lowest CVs for the sharks. The blue sharks had CVs near 0.3, whereas the others did not. Swordfish had CVs below 0.3 and, unlike the other species; the weight-based auxiliary variables provided the greatest precision.

PRECISION

The precision of the mean number of discards per set is related to the precision of the estimated total number by a factor. The precision of the mean number discarded was determined using Monte Carlo simulation. Figure 34 and Figure 35 show how the estimate of the mean and its 95% confidence interval change as the observed portion of the fishery increased from 10% to 100% and as the number of simulated fishing sets increased from 1000 to 2000 per year. This range in fishing sets represented the historical range.

The figures indicate that the initial estimate of the mean number discarded does not vary with changing coverage or size of the fishery. The confidence intervals narrowed rapidly up to 20% coverage and the change was minimal after 40% coverage. The intervals became wider as the fishery shrunk in size. The frequency with which a species was caught is reflected by the magnitude of the estimate of the mean. Note that for species like swordfish that were harvested, the estimated mean number is a combination of what was kept and discarded.
The precision of the estimated mean and also the estimated total number was represented by the CV. The coverage needed to achieve a CV of 0.3 was between 20% and 30% when the fishery had 1000 sets. This level of precision could be achieved for all species tested at 10% coverage if the fishery had 2000 sets. The bias in the estimates was negligible for all species and levels of coverage under the two fishing scenarios.

DISCUSSION

The eastern Canadian pelagic longline fishery is in a period of shrinking effort that began in 2007. There were fewer vessels in 2010 and fewer sets, trips and sea days than in 2006. All areas have shown this decline with the exception of 5ZY6DE, which experienced increased effort. East of 60° West longitude the fishing dropped by 75% and in 4XW effort dropped by 50%. The decline was most noticeable in vessels under 57.2 feet in length.

The observer coverage from 2002 to 2010 has not been a constant proportion of the fishing effort. It has not been any less than 4 or 5% and recently the coverage has been approximately 10%. In 2002 it was over 20%. The percent coverage depended somewhat on whether the sample unit was sets, trips or sea days; however, all measures give similar looking coverage trends over time. Each of these metrics is related to each other and should be considered when evaluating the coverage. Operationally, the level of at-sea coverage is based on the previous year's actual sea days and relates directly to the cost of the observer program. However, the observers must be allocated to trips which are of unknown duration and fishing intensity and must conform in cost to the sea day totals established in the previous year. This constraint may affect the allocation of observers to trips, particularly late in the season. Additionally, though trips are often considered to be the de facto sampling unit, they are not necessarily the most practical choice because they are not confined to occur within the areas or time periods of interest to science. Consequently, issues of coverage within time and area sub domains are best addressed using sets.

An examination of the observer coverage within a fishing season revealed that the allocation of observers to trips may have been hampered by low sea day allotments especially in the face of changing effort in the fishery. Years of low annual coverage were typically equated with gaps in the sampling and it was possible for the sampling to be out of synchrony with the fishing. It is understandable that this might occur when the pool of observer sea days is small and the timing of fishing is unpredictable. Higher coverage did yield a more representative sample but unsampled times did still occur. An examination of the coverage within areas of the fishing domain revealed an absence of sampling in some areas for large portions of the fishing season particularly when the overall coverage was low. Even in years of high coverage significant areas and time periods could go unsampled.

The absence of sampling is more problematic than under or over sampling as it represents a complete absence of information. Assumptions that adjacent areas or time periods have the same properties in terms of the distribution of a species and its vulnerability to gear should not be hastily made. In a report by Fairfield Walsh and Garrison (2006), the authors attempt to deal with the difficulty of estimating the bycatch in unobserved quarters and propose multiple solutions that all introduce unacceptable bias in the estimates. Understanding what causes the absence of sampling may help make it more representative of the fishing. The small size of some vessels and their life boats limits which vessels can accommodate an observer. Possibly these small vessels fish at times and in places where there has been an absence of sampling. It was observed that the larger vessels were the preferred platform of observers, but it was not clear what the relationship was to the gaps in the sampling. Putting observers on the smaller vessels may solve both problems.

In an effort to structure the sampling, DFO Science provided advice as to how many observer days should be allocated to each month and area (Table 1). These rules were developed for 20% observer coverage and have been in existence through periods of 5% coverage. It was observed by Gavaris and Smith (1987) that when attempting to execute a stratified random sampling design for improving the precision of cod abundance estimates, a sub-optimal allocation of samples to strata resulted from trying to allocate a limited number of samples to the strata in proportion to stratum size. This sub-optimal allocation resulted in the prescribed stratified sampling design having inferior precision to simple random sampling. Strictly following the science advice may be leading to a less representative sampling of the fishery when handicapped by too few observer days to allocate. It was observed that the coverage in each month matched the advice fairly well and yet in reality whole areas and or time periods went unsampled. The advice likely needs to be adapted to a lower level of observer coverage and incorporate more flexibility and fewer strata to allow the observers to see all the fishing in a representative way.

Tests were used to determine if the sampling matched schemes based on a) observing a constant proportion of fleet effort, b) following the science advice in Table 1 or c) adjusting the science advice to reflect the relative effort in each area. These tests were applied to the sample frequencies in each month across areas, each area across months and within each valid month area combination. From the test results, it did not appear that any of the three sampling strategies were being applied (successfully) to months and areas concurrently. With respect to the sampling of areas, the observers seemed to be allocated with a view to observing a constant proportion of the catch, whereas the allocation of observers to months seemed guided by the science advice though they were not significantly in agreement with it. Thus one must conclude that if there was a sampling plan it was either a) not of the ones tested, b) one of the ones tested but difficult to implement or c) loosely based on one of the ones tested.

Given the features of the sampling described above, it was obvious that some attention must be given to the details of the sampling before one attempted to estimate discard weights and numbers. The population that the sampling was intended to represent may need to be narrowed when scaling the discards to the total fleet, not just because samples are lacking in important times or areas, but because a given species may only be resident in a small portion of the fishing domain for a short period of the year. Diaz (2010) also emphasized that the sample should be related to the appropriate population so that the perception of the coverage required to achieve a given level of precision of our estimates is accurate. In this study, the ratio method was used to estimate total discards without these considerations and could have yielded smaller total discard estimates if they were taken into account. Also, being too generous with the size of the domain can cause positively skewed catch data (e.g., many zero counts) that lead to confidence probabilities which do not encompass zero. This was a feature of the rarely caught species.

A full evaluation of methods that could yield estimates of total discards was not performed. A design-based method of inference, the ratio method, was used to establish the degree of precision that could be achieved using various auxiliary variables. In a simulation study using data from the Gulf of Mexico longline fishery (Beerkircher et al., 2009), the ratio estimation method was shown to provide a fairly constant ratio of bluefin tuna discards to number of sets over the full range of observer coverage (4 to 100%). The estimates of total discard were found to be on average unbiased over this range and the precision improved dramatically up to 40% coverage. In this study, it was evident that other factors were as important as coverage in affecting precision. For example, although many of the auxiliary variables provided similar estimates of total discards, the proper choice of auxiliary variable could reduce the confidence interval for the estimates in certain cases. This occurred where there was a decent correlation between the sample discards and the auxiliary variable. Harvest species had improved precision using a weight-based-variable while the other species tended to have a better relationship with an effort-based variable like the number of hooks. Judging by the weak correlation between the sample discards and the auxiliary variables for many of the species, there could be many cases where another method would be a better option for estimating total discards. Time limitations did not allow an exploration of these options.

Factors that affect the accuracy of the estimated quantity of a species discarded, do so by introducing a consistent positive or negative bias. Typically, the causes of bias have been classified into three broad categories as: "(1) errors in the sampling frame, (2) bias caused by how vessels within the sampling frame are selected for observation (i.e., observed vessels may not be representative of the general fleet), and (3) bias caused by changes in fishing behavior in the presence of observers" (Vølstad and Fogarty, 2006). The bias can often be large. For example, the observer effects in the Gulf of St. Lawrence fisheries were determined to be an underestimation of discards of 16% and 9% in the cod fixed- and mobile-gear fisheries, respectively (Benoît and Allard, 2009). In the Hawaiian commercial longline fishery, Walsh et al. (2002) found that the catch of blue shark was under-reported by 23.9% when observers were present yet no systematic over- or under-reporting of marlins was detected (Walsh et al., 2005). The biases, when they exist, are a permanent feature of the data and are difficult to remove post hoc during data analysis and rather easy to avoid during the sampling program planning and implementation phases.

The precision of the estimated quantity of a species discarded was determined under scenarios of high and low fishing at different levels of observer coverage using a Monte Carlo simulation of simple random sampling from the fishery. The simulations suggested that if the sampling of the fishery was random, the level of coverage need only be about 20% to achieve a precision of at least 30% for all the species tested, even under the low fishing scenario. In a similar simulation analysis of precision of bycatch rate estimates by Kell et al. (2010), it was shown that in order to achieve a level of precision of 30% in the estimate, both the encounter probability of the species and the variation in the catch for the positive sets were important. As the CV of the positive sets increased, so must the coverage in order to maintain the same level of precision. Likewise, as the encounter probability decreased, the coverage must increase to maintain the same level of precision. As noted here and by Amandè et al. (2010), the coverage rate and catch data are not the only factors that influence the precision of the estimates, the size of the fishery in terms of the absolute number of trips or sets is also important.

In summary, the major concern arising from this examination of the observer coverage of the pelagic longline fishery was not necessarily the size of the sample or the quality of the information obtained but that the sample may not always be representative of the fishing. Care must be taken to ensure that the sample is not asked to represent a component of the fishery, region or time period where there is no data. Design-based and model-based methods of inference may improve the precision of estimates made under these circumstances but can not avoid being inaccurate.

CONCLUSIONS AND RECOMMENDATIONS

1. The pelagic longline fishery is changing in terms of the degree of activity in the areas and months it has traditionally fished. Observer deployments should reflect the change.
2. The sampling sometimes misses important areas and time periods. The allocation of observer time should be reviewed to see if the sample can be made more representative of the fishing. Real time evaluation of the progress of the fishery relative to the allocation of observer time should be common practice and requires better communication between DFO Science and the observer contracting company. A post season evaluation of the coverage should be conducted to ensure the sampling is sensitive to the changing nature of the fishery and optimal for species that are important.
3. Observers spend a disproportionate amount of their time on large vessels and tend to be on the longer duration trips when on small vessels. There is a need to determine how small vessels contribute to the total discards and then find ways to observe their catch.
4. Observer coverage followed the DFO Science advice of 2000 on how to sample the fishery. This rigid stratification scheme may have constrained the sampling too much. The sampling did not always appear to represent the fishing well, especially when coverage was near 5%. The advice was based on the state of the fishery in 2000 and on observer coverage of 20% and needs to be updated. A logistically simple sampling plan needs to be devised that adjusts to the changing activity of the fishery. Rago et al. (2005) provide a methodology for allocating finite resources to meet multiple requirements for stock assessment and protected species evaluation. Cotter (2002) describes using the ‘probability proportional to size’ (PPS) sampling method in the English North Sea cod fishery to overcome a problem with stratification and a small number of observers.
5. High observer coverage will improve the precision of estimates, but other factors such as the size of the fishery, encounter probability of the species and the variability of the catch in the positive sets are equally important. Consequently, it is important that coverage increase as the size of the fishery declines.

6. The ratio estimation method may not be appropriate for every species in all years. Other methods may improve precision. The choice of auxiliary variable will affect the precision of the estimate. Regardless of which technique is used, caution must be exercised before extrapolating results to areas or time periods not observed. Given the species specific nature of the estimation process, the onus is on the researcher to ensure that the optimal method is employed. More time needs to be devoted to suggesting plausible alternatives for estimating total discards.
7. Under a low fishing scenario, observer coverage of about 20% achieved a CV of at least 30% for all species tested. Guidance on the minimum levels of precision exist in the literature; however, the Canadian pelagic longline fishery should have its own species specific precision targets that take into consideration the rarity of the species in our waters and the risk of extinction due to its fishing practices. Babcock et al. (2003) have suggested 50% coverage to estimate bycatch of rare species (defined as less than 0.1% of catch). The National Marine Fisheries Service (NMFS, 2004) more appropriately specifies a precision target to be 20 to 30%, rather than setting the level of coverage since improvements in precision can be achieved from actions other than increasing observer coverage. Practically, in a situation where bluefin tuna made up 2.5% of the catch, Beerkircher et al. (2009) found that observer coverage of 30% to 40% would give a CV of 20%.

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Table 1. Proposed observer deployment scheme based on 20% coverage.

Month	# Observed Trips proposed	Description/Rationale*
May	2-3	1 per area for this month
June	4-6	2 per area for this month
July	6-9	3 per area for the intense fishing months
August	6-9	3 per area for the intense fishing months
September	6-9	3 per area for the intense fishing months
October	4-6	2 per area for this month
November	2-3	1 per area for this month
Total	30-45	All months and areas sampled, plus ~ 10% trips sampled from high intensity fishing months.

* Areas: Western Scotian Shelf (west of 60°); Eastern Scotian Shelf (east of 60°); Grand Banks.
Note. Not all months or areas will have fisheries, and will therefore not have Observer coverage.

Table 2. The nominal estimates of observer coverage for the pelagic longline fishery from 2002 to 2010.

	SETS		TRIPS		SEA DAYS	
Year	Obs/Total	Coverage (%)	Obs/Total	Coverage (%)	Obs/Total	Coverage (%)
2002	334/1459	22.9	48/213	22.5	601/2022	29.7
2003	117/1407	8.3	18/194	9.3	214/1955	10.9
2004	80/1560	5.1	12/239	5.0	138/2216	6.2
2005	102/1775	5.7	13/247	5.3	171/2567	6.7
2006	131/1803	7.3	17/268	6.3	208/2604	8.0
2007	87/1501	5.8	12/212	5.7	138/2231	6.2
2008	49/1174	4.2	11/157	7.0	85/1683	5.1
2009	115/1081	10.6	19/155	12.3	189/1601	11.8
2010	108/971	11.1	19/166	11.4	166/1454	11.4

Table 3. The number of observed and total trips for the pelagic longline fishery within NAFO divisions from 2002 to 2010.

Year	3KLOMN	3P4V	4W	4X	5ZY6DE
2002	26/52	3/10	30/183	26/152	11/26
2003	8/60	1/33	17/243	4/69	1/24
2004	8/42	2/12	10/217	1/149	1/30
2005	3/56	3/46	16/264	6/118	2/59
2006	10/44	4/30	18/257	5/166	1/35
2007	4/36	2/42	14/226	2/132	1/44
2008	2/23	-	11/156	2/95	2/37
2009	1/25	4/36	14/96	12/97	6/41
2010	1/18	-	24/34	6/86	1/51

Table 4. The nominal estimates of observer coverage (%) for the pelagic longline fishery within NAFO divisions from 2002 to 2010.

Year	3KLOMN	3P4V	4W	4X	5ZY6DE
2002	50.0	30.0	16.4	18.4	42.3
2003	13.3	3.0	7.0	5.8	4.2
2004	19.0	16.7	4.6	0.7	3.3
2005	5.4	6.5	6.1	5.1	3.4
2006	22.7	13.3	7.0	3.0	2.9
2007	11.1	4.8	6.2	1.5	2.3
2008	8.7	-	7.1	2.1	5.4
2009	4.0	11.1	14.3	12.4	14.6
2010	5.6	-	17.9	7.0	2.0

Table 5. Goodness-of-fit tests comparing observed sets to expected counts under three null hypotheses[2,3,4] and for three families of tests[1]. P-values are compared against the family-wise error corrected significance level of 0.017. Bold p-values indicate that H_o could not be rejected.

Model[1]	Coverage	Year	Chi-square[2]	p-value[2]	Chi-square[3]	p-value[3]	Chi-square[4]	p-value[4]
Area x Month	0.24	2002	125.2	0.001	465.4	0.001	326.7	0.001
	0.08	2003	65.7	0.006	163.6	0.001	117.8	0.001
	0.06	2004	94.82	0.002	108.3	0.001	139.5	0.001
	0.07	2005	68.19	0.001	151.7	0.001	131.5	0.001
	0.07	2006	333.20	0.001	149.9	0.001	344.5	0.001
	0.06	2007	103.75	0.001	125.2	0.001	100.8	0.001
	0.07	2008	248.17	0.001	82.8	0.001	181.4	0.001
	0.14	2009	48.06	0.003	288.5	0.001	135.1	0.001
	0.17	2010	76.70	0.001	302.0	0.001	90.9	0.001
Area	0.24	2002	7.7	**0.020**	318.4	0.001	22.1	0.001
	0.08	2003	5.4	**0.071**	75.1	0.001	5.4	**0.067**
	0.06	2004	33.3	0.001	50.5	0.001	36.8	0.001
	0.07	2005	21.8	0.002	66.8	0.001	21.7	0.001
	0.07	2006	158.4	0.001	24.3	0.001	163.2	0.001
	0.06	2007	5.3	**0.067**	54.8	0.001	6.9	**0.038**
	0.07	2008	38.2	0.001	14.6	0.004	52.4	0.001
	0.14	2009	2.6	**0.273**	117.4	0.001	3.9	**0.170**
	0.17	2010	8.5	**0.021**	217.5	0.001	11.8	0.009
Month	0.24	2002	69.36	0.001	46.27	0.001	2048.91	0.001
	0.08	2003	16.03	**0.017**	46.54	0.001	34.64	0.003
	0.06	2004	43.01	0.001	21.00	0.004	124.64	0.001
	0.07	2005	7.82	**0.224**	39.07	0.001	3.52	**0.705**
	0.07	2006	102.15	0.001	67.49	0.001	1201.21	0.001
	0.06	2007	53.68	0.001	44.44	0.001	225.39	0.001
	0.07	2008	163.20	0.001	57.98	0.001	1068.95	0.001
	0.14	2009	35.02	0.003	60.71	0.001	65.63	0.003
	0.17	2010	52.47	0.002	24.51	0.003	70.39	0.005

---

[1] These are the separate family of tests for which the observed count was compared to expectation under the 3 null hypotheses.

[2] H_o : Constant proportion of fishing.

[3] H_o : Science advice.

[4] H_o : Science advice with area weighting.

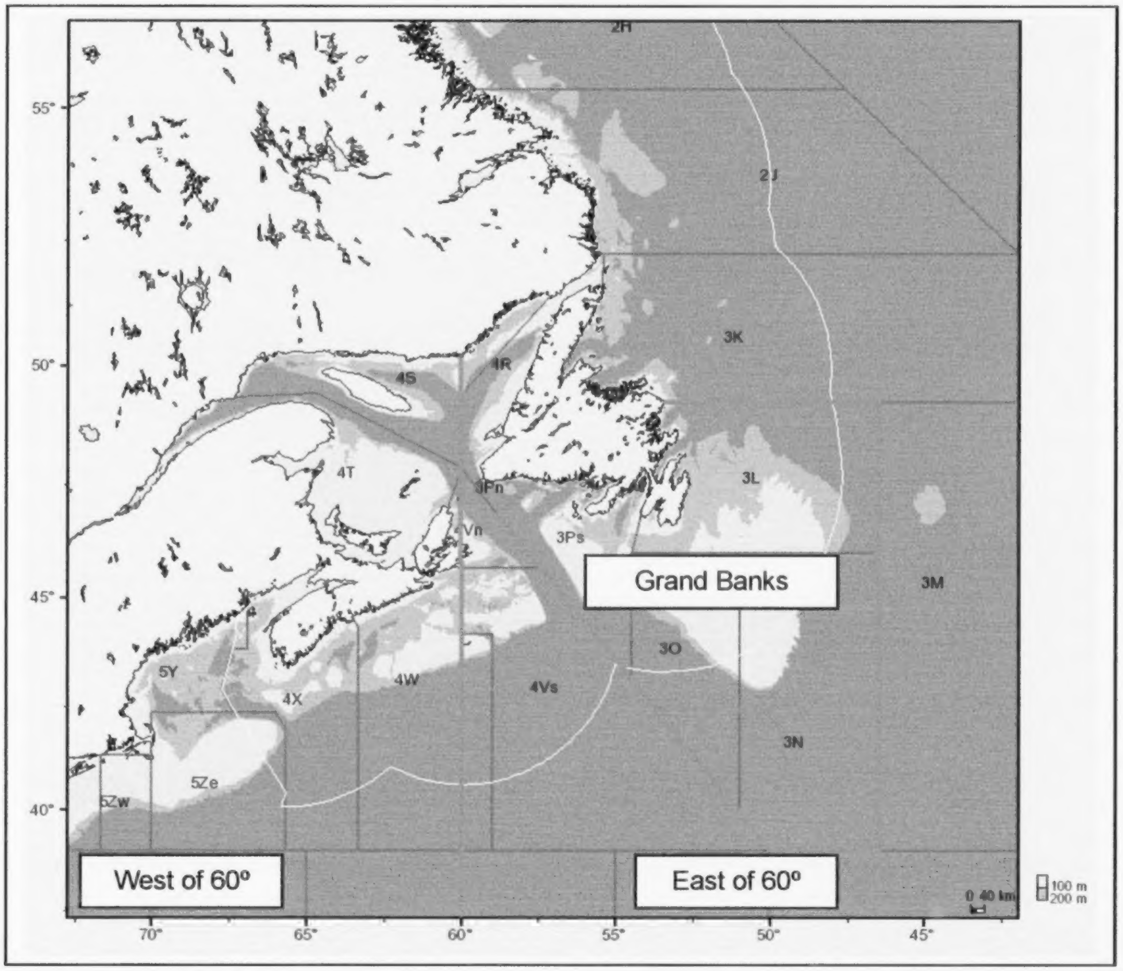


Figure 1. The geographical division of the pelagic longline fishery observer coverage as per science advice of 2000 (J. Porter, internal communication). Areas East and West are separated by 60°W longitude, while Grand Banks follows NAFO division boundaries.

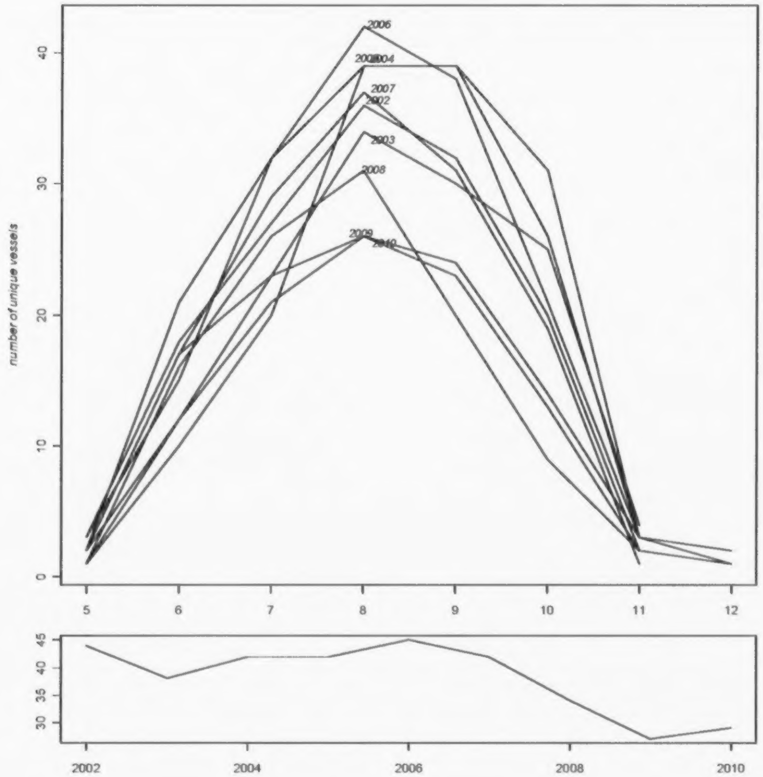


Figure 2. The number of unique vessels fishing with pelagic longline gear in each month for 2002 to 2010 (upper) and total in each year (lower).

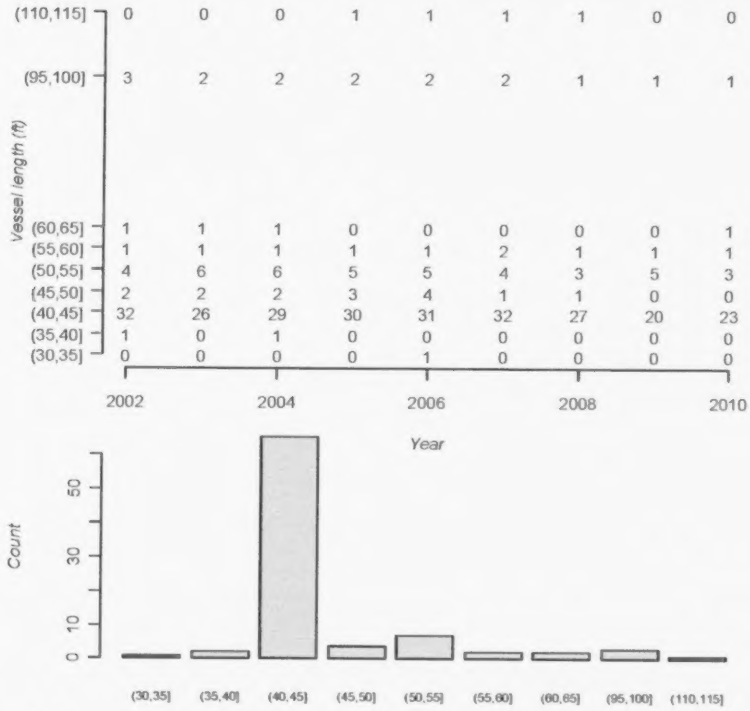


Figure 3. Vessel length class frequency for 2002 to 2010 (upper) and composite frequency (lower).

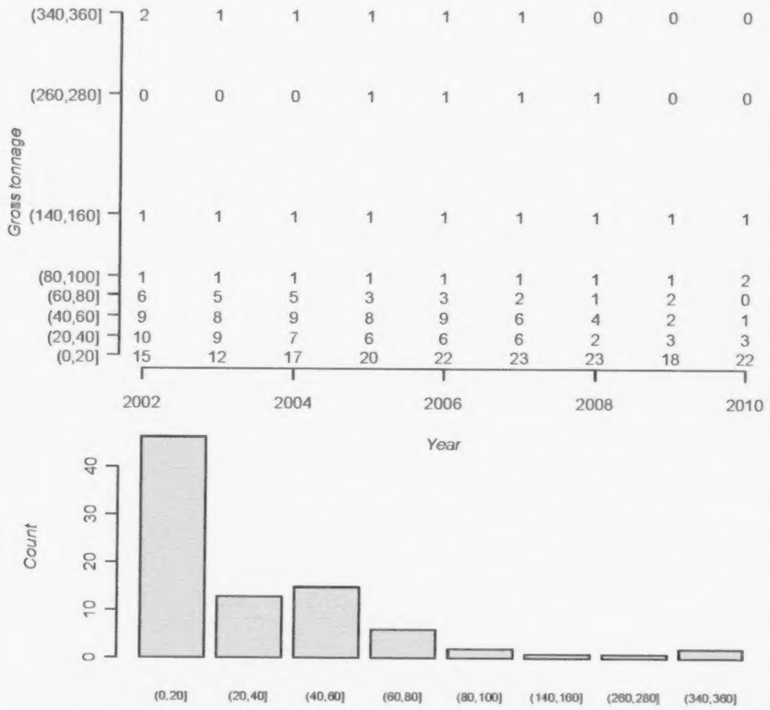


Figure 4. Vessel gross tonnage class frequency for 2002 to 2010 (upper) and composite frequency (lower).

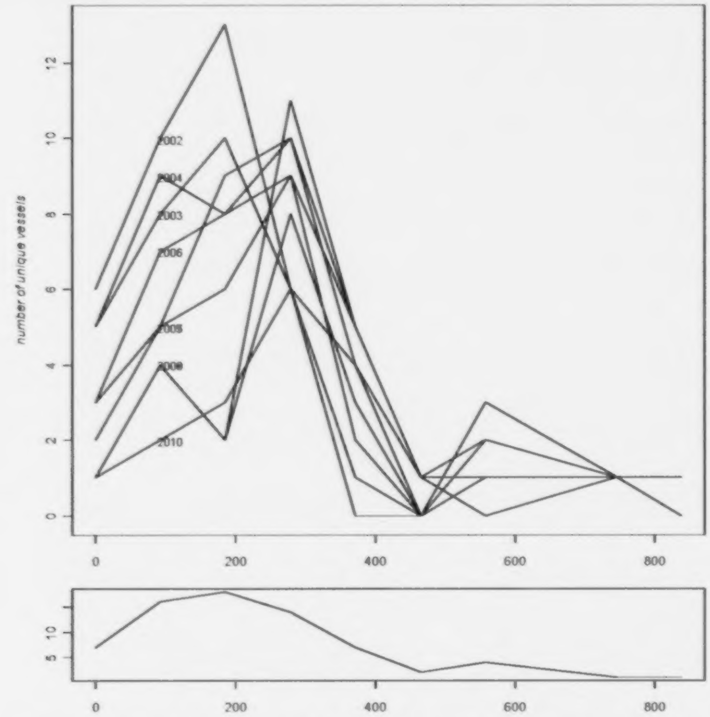


Figure 5. Brake horsepower of vessels by year (upper) and across years (lower).

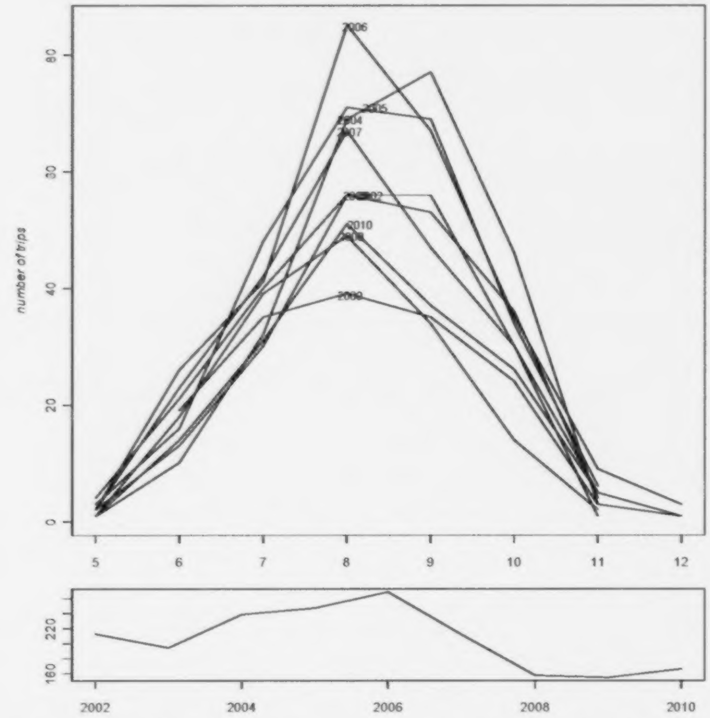


Figure 6. Total trips for vessels in the pelagic longline fishery by month for each year (upper) and by year (lower).

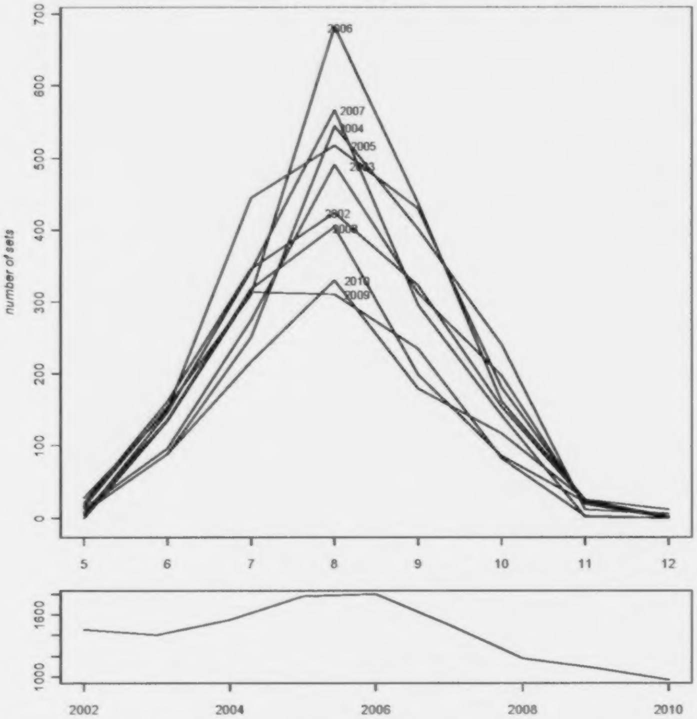


Figure 7. Total sets for vessels in the pelagic longline fishery by month (upper) and by year (lower).

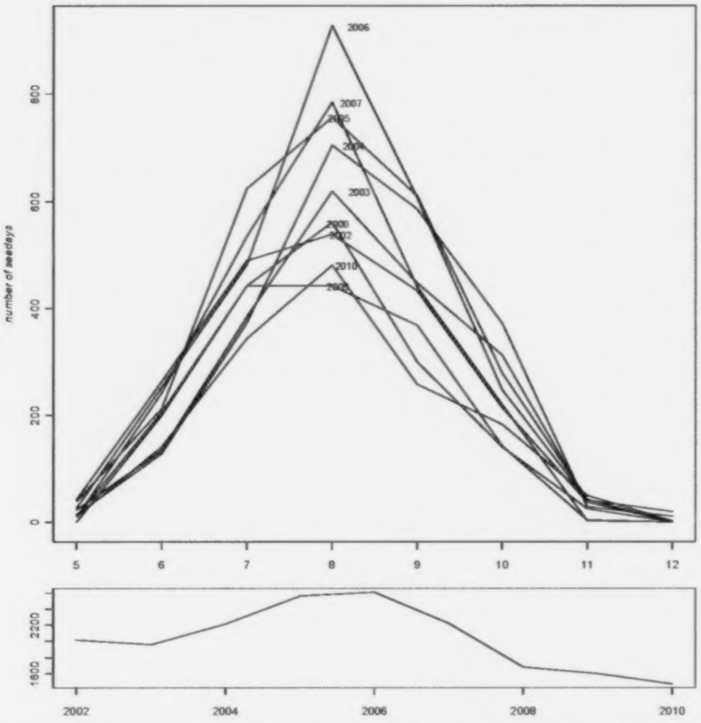


Figure 8. Total sea days for vessels in the pelagic longline fishery by month (upper) and by year (lower).

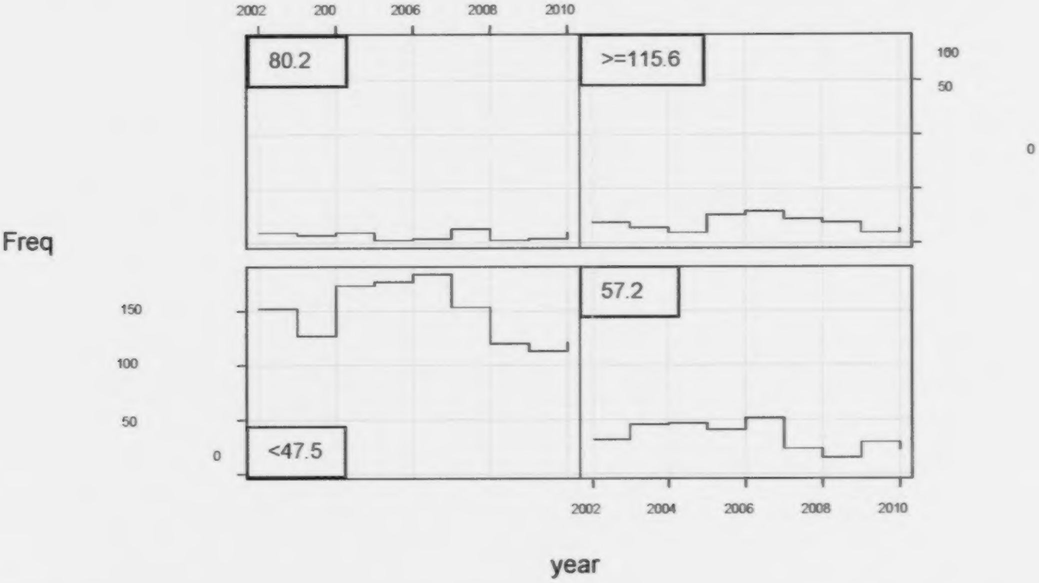


Figure 9. Frequency of trips by vessel length class (ft) and year.

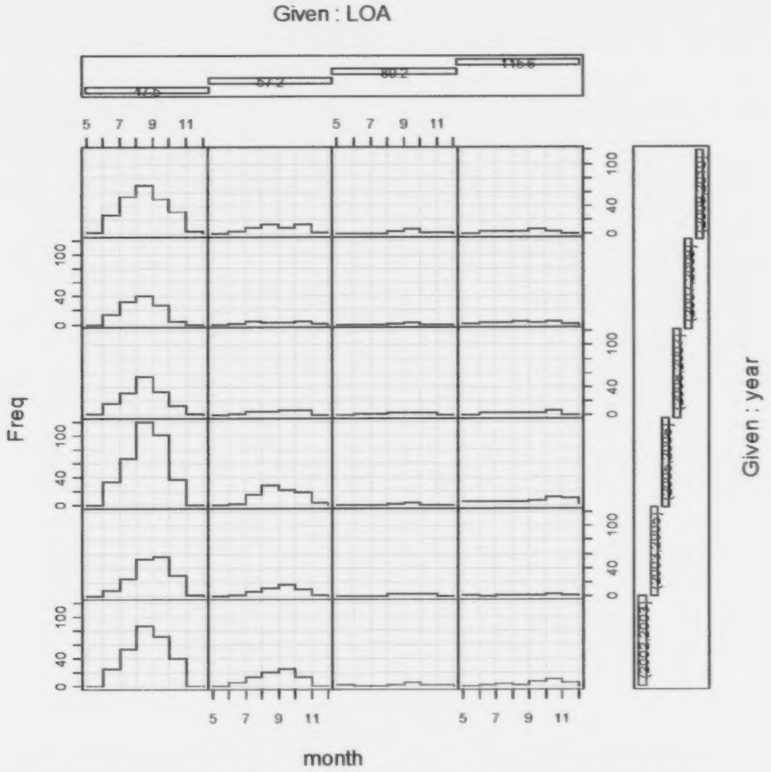


Figure 10. Frequency of trips by vessel length class, year and month.

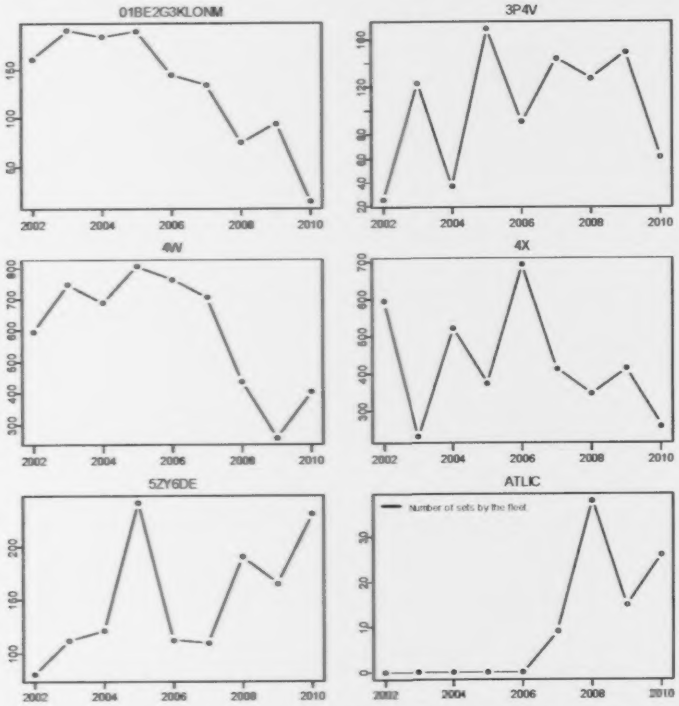


Figure 11. Total sets by area and year for the pelagic longline fishery.

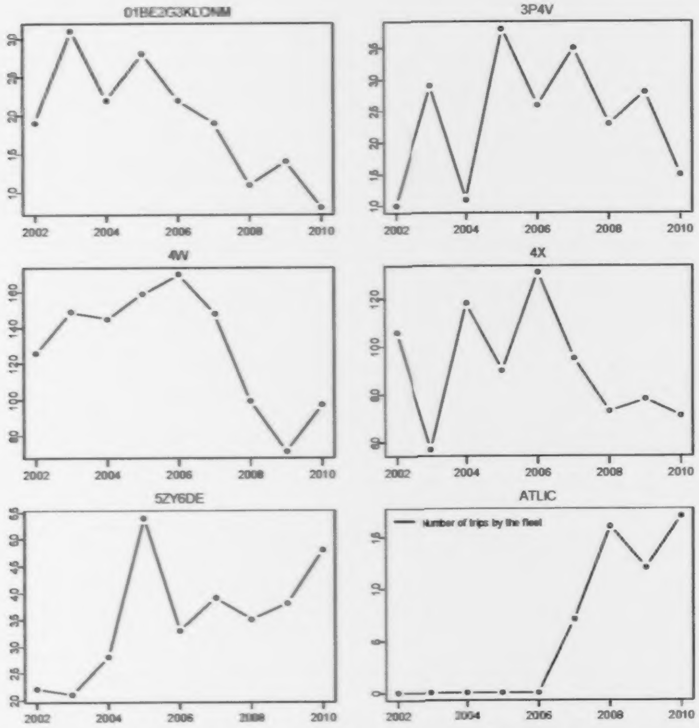


Figure 12. Total trips by area and year for the pelagic longline fishery.

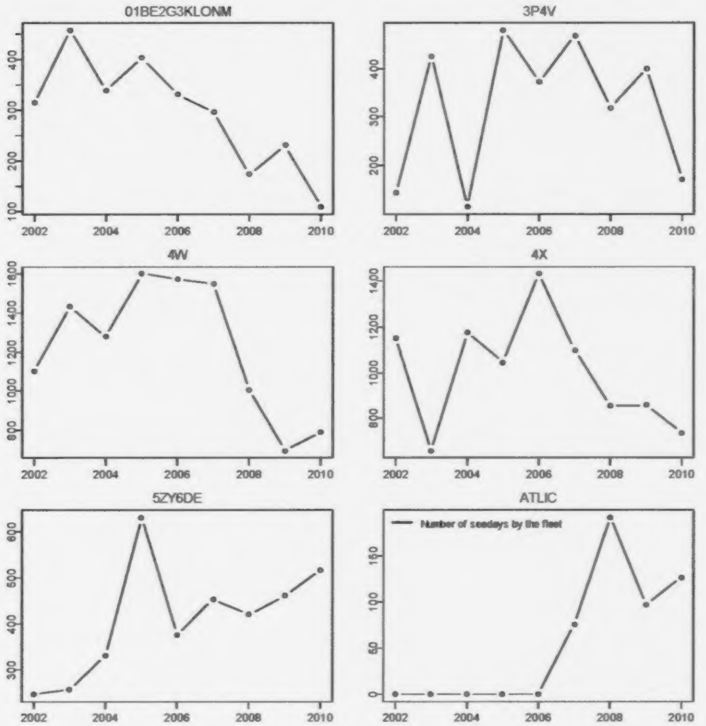


Figure 13. Total sea days by area and year for the pelagic longline fishery.

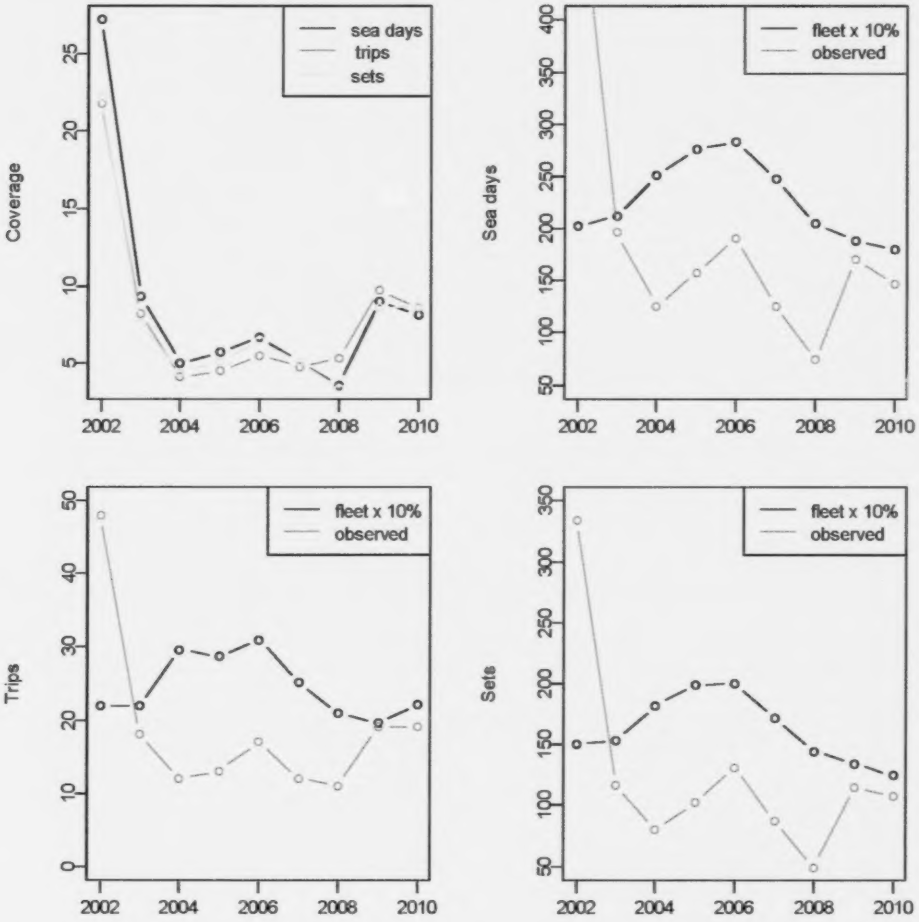
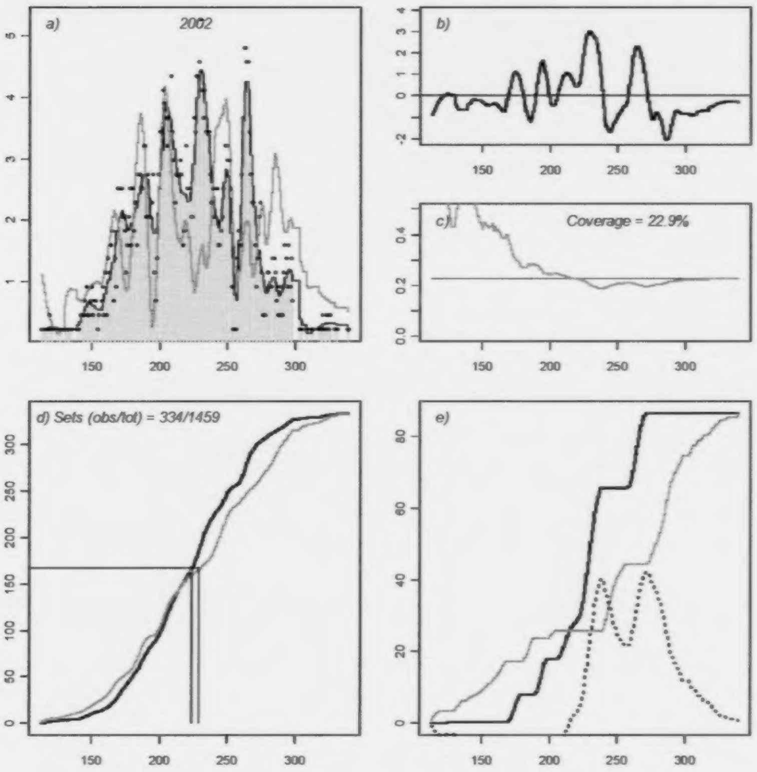
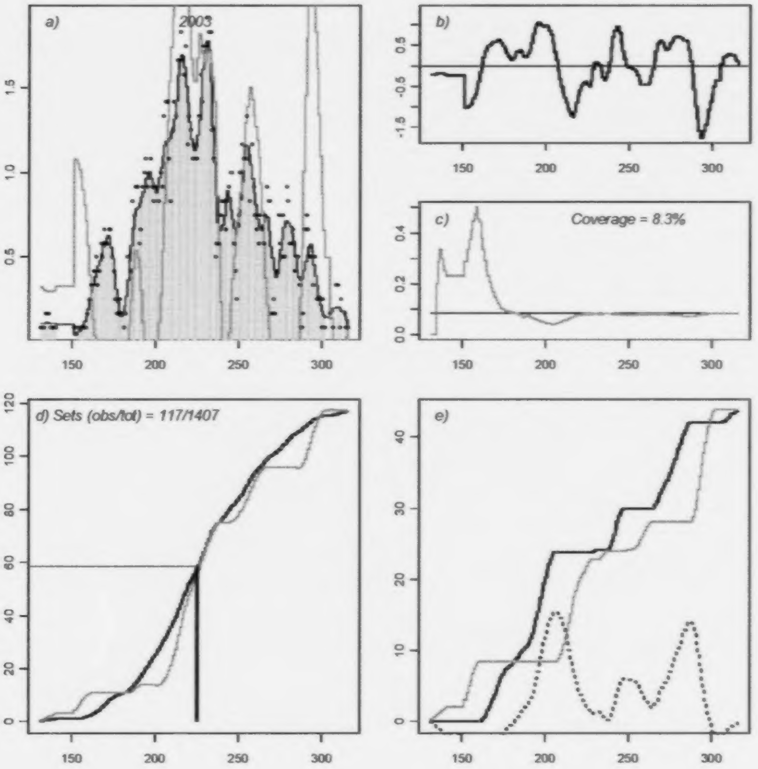
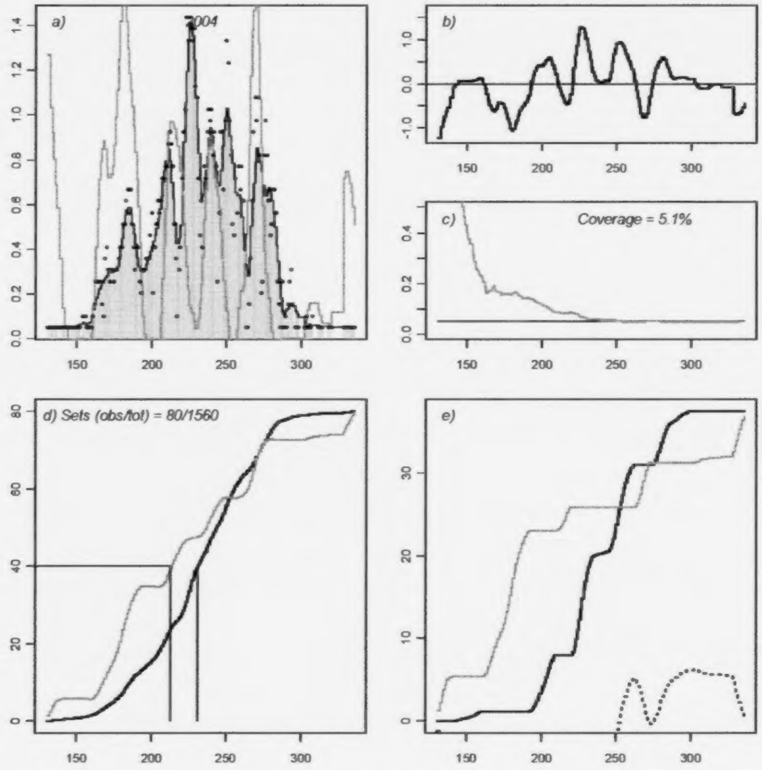
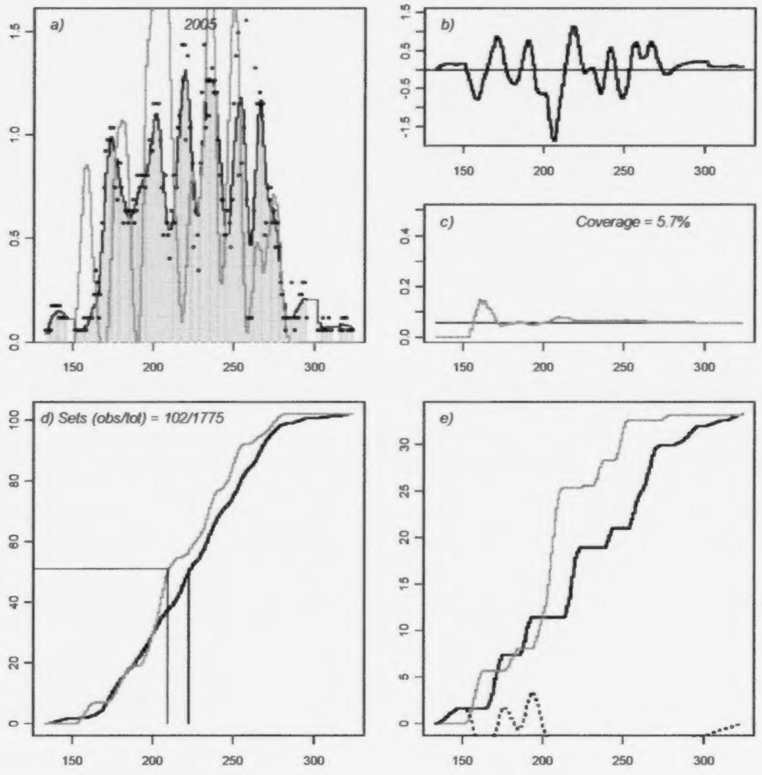


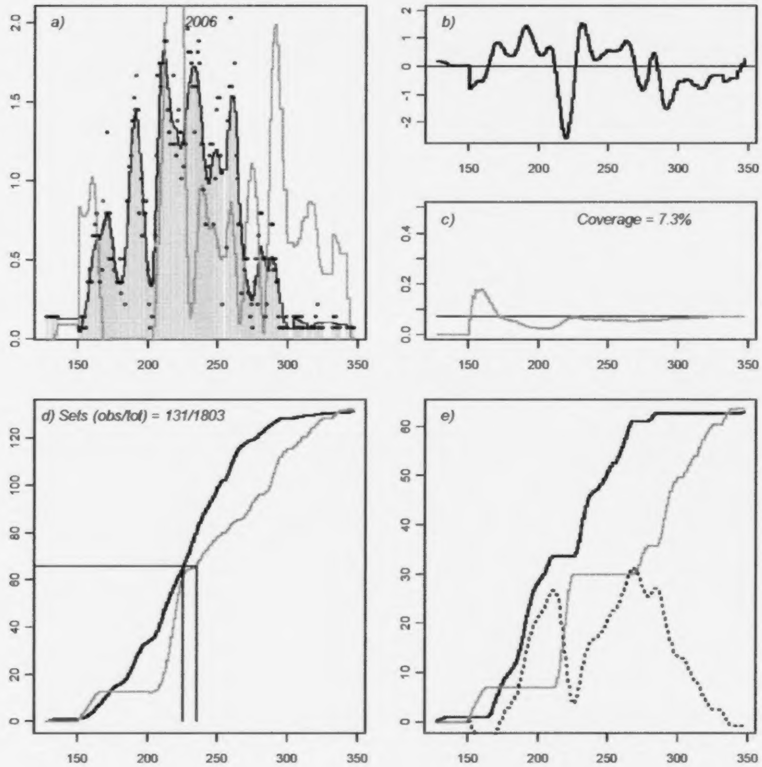
Figure 14. The proportion of the pelagic longline fleet sampled (coverage) according to three sampling metrics (sea days, sets and trips). The nominal amounts observed are also shown relative to 10% of the fleet total.

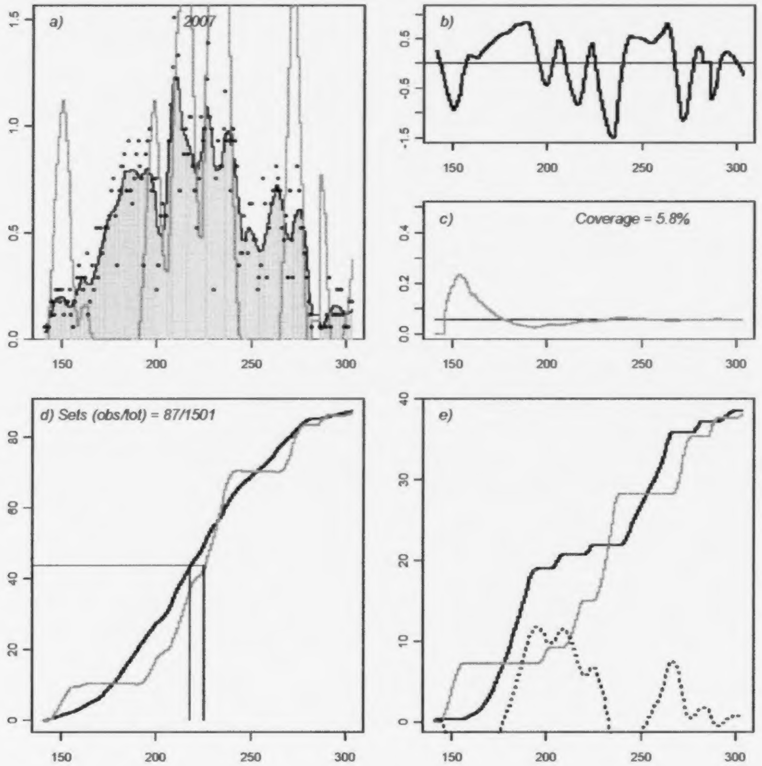

a)
2002
b)
c)
Coverage = 22.9%
d) Sets (obs/tot) = 334/1459
e)
150
200
250
300

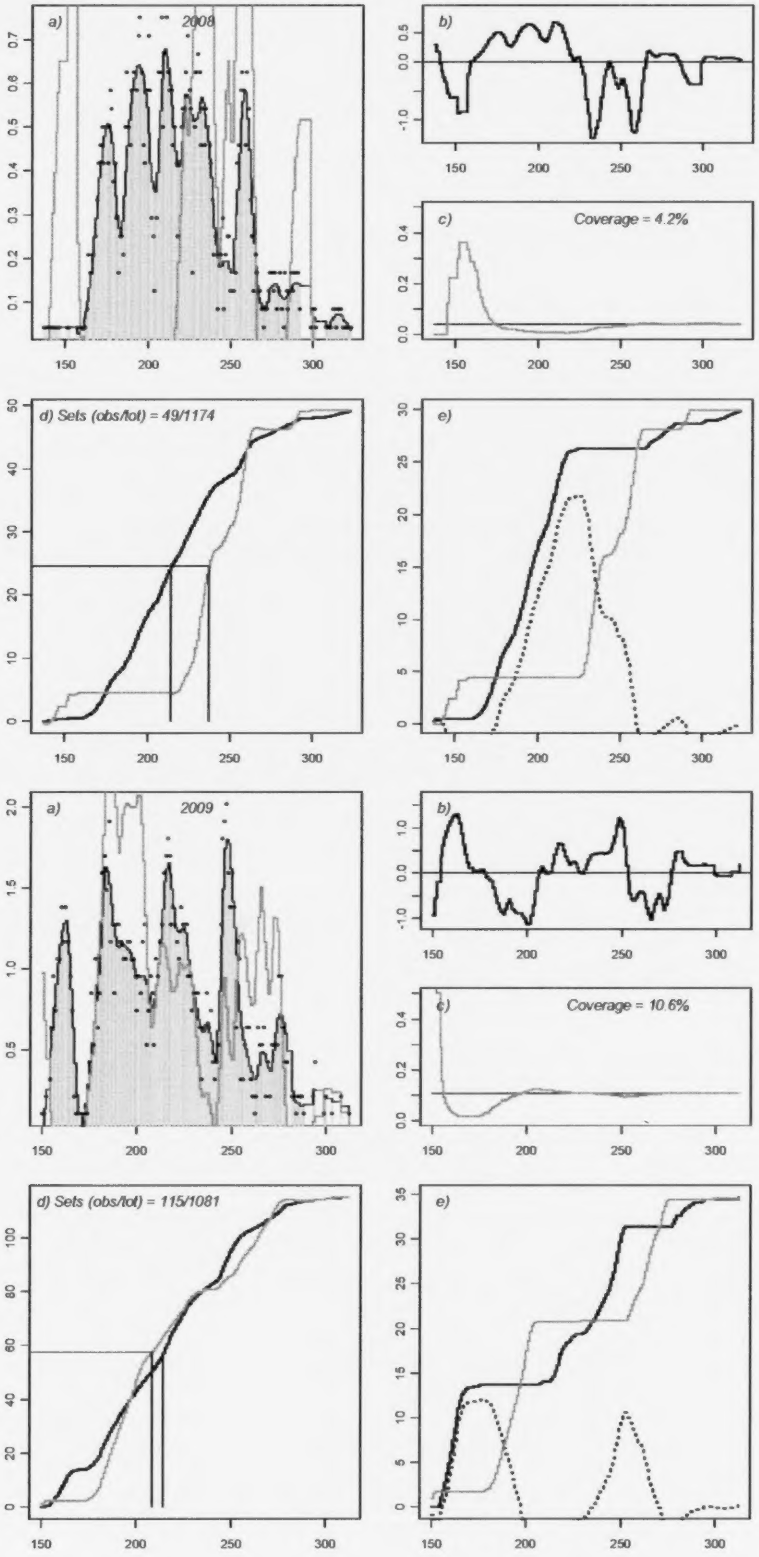

a)
2003
b)
c)
Coverage = 8.3%
d) Sets (obs/tot) = 117/1407
e)
150
200
250
300


a)
2004
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
150
200
250
300
b)
-1.0
0.0
1.0
150
200
250
300
c)
Coverage = 5.1%
0.0
0.2
0.4
150
200
250
300
d) Sets (obs/tot) = 80/1560
0
20
40
60
80
150
200
250
300
e)
0
10
20
30
150
200
250
300


a)
2005
0.0
0.5
1.0
1.5
150
200
250
300
b)
-1.5
-0.5
0.5
1.5
150
200
250
300
c)
Coverage = 5.7%
0.0
0.2
0.4
150
200
250
300
d) Sets (obs/tot) = 102/1775
0
20
40
60
80
100
150
200
250
300
e)
0
5
10
15
20
25
30
150
200
250
300


a)
2006
2.0
1.5
1.0
0.5
0.0
150
200
250
300
350
b)
2
1
0
-1
-2
c)
Coverage = 7.3%
0.4
0.2
0.0
d) Sets (obs/tot) = 131/1803
120
100
80
60
40
20
0
e)
60
50
40
30
20
10
0


a)
2007
1.5
1.0
0.5
0.0
150
200
250
300
b)
0.5
-0.5
-1.5
c)
Coverage = 5.8%
0.4
0.2
0.0
d) Sets (obs/tot) = 87/1501
80
60
40
20
0
e)
40
30
20
10
0


a)
2008
0.7
0.6
0.5
0.4
0.3
0.2
0.1
150
200
250
300
b)
0.5
0.0
-1.0
c)
Coverage = 4.2%
0.4
0.2
0.0
d) Sets (obs/tot) = 49/1174
50
40
30
20
10
0
e)
30
25
20
15
10
5
0
a)
2009
2.0
1.5
1.0
0.5
b)
1.0
0.0
-1.0
c)
Coverage = 10.6%
0.4
0.2
0.0
d) Sets (obs/tot) = 115/1081
100
80
60
40
20
0
e)
35
30
25
20
15
10
5
0

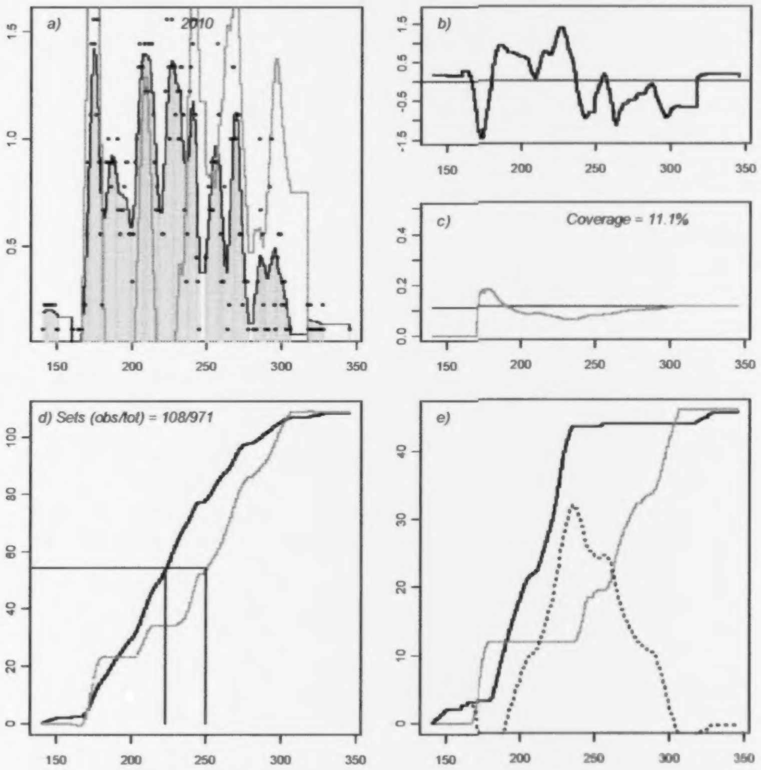
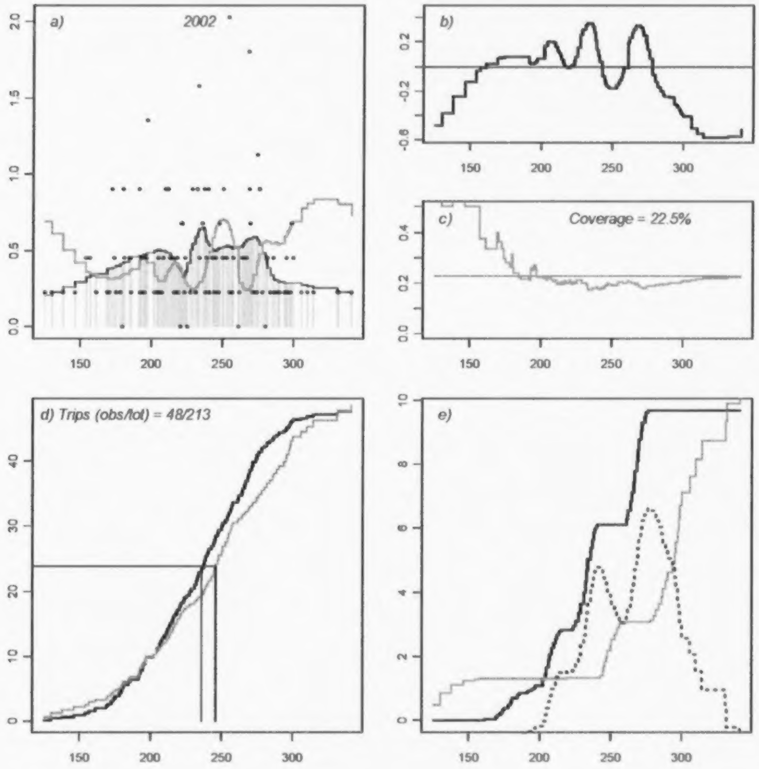
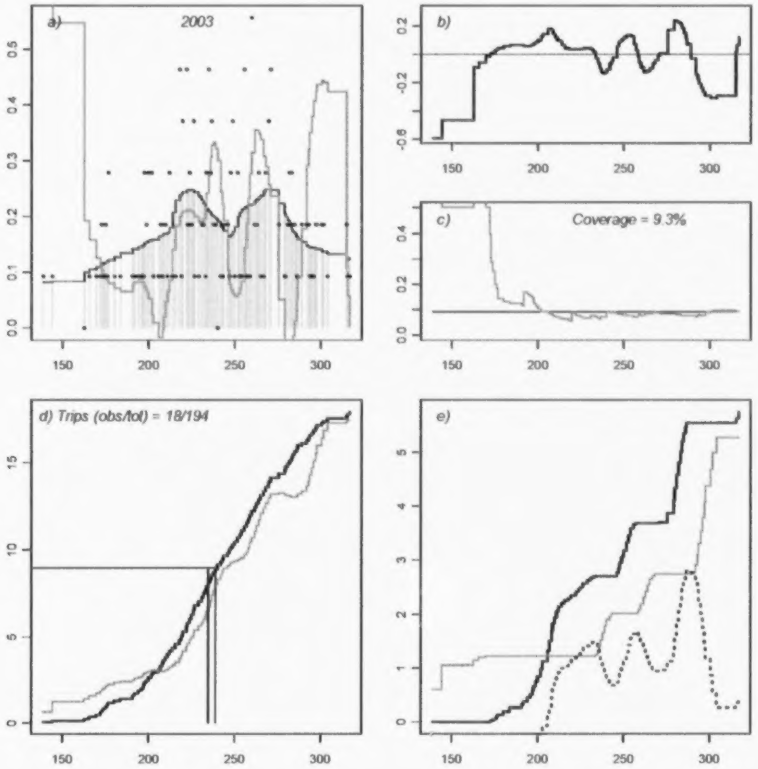
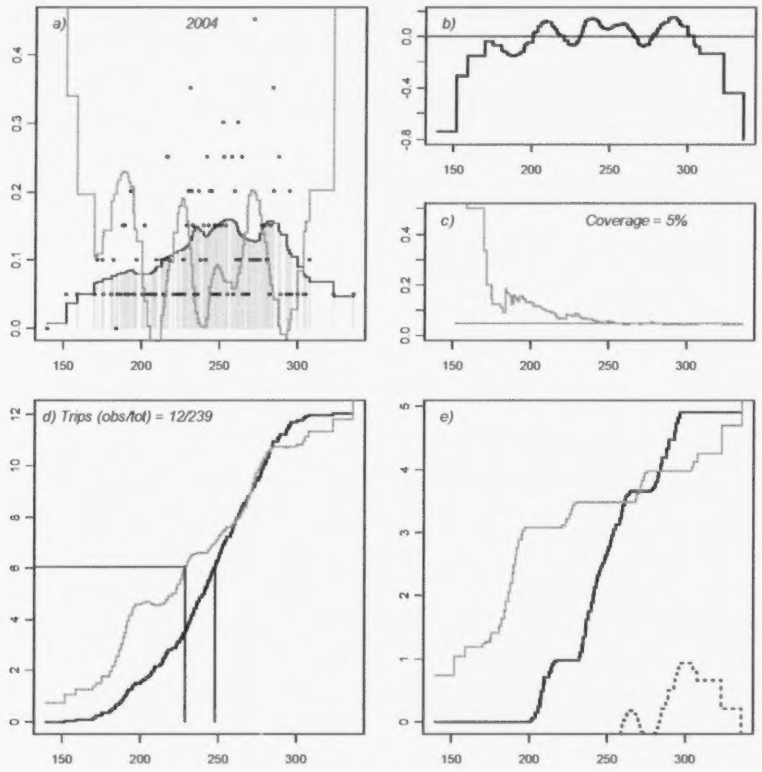
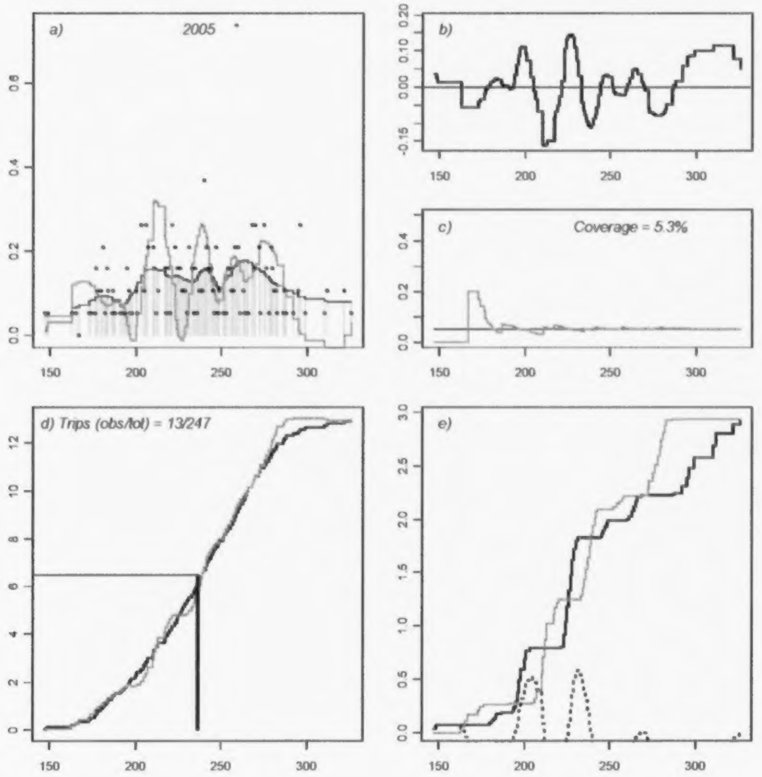


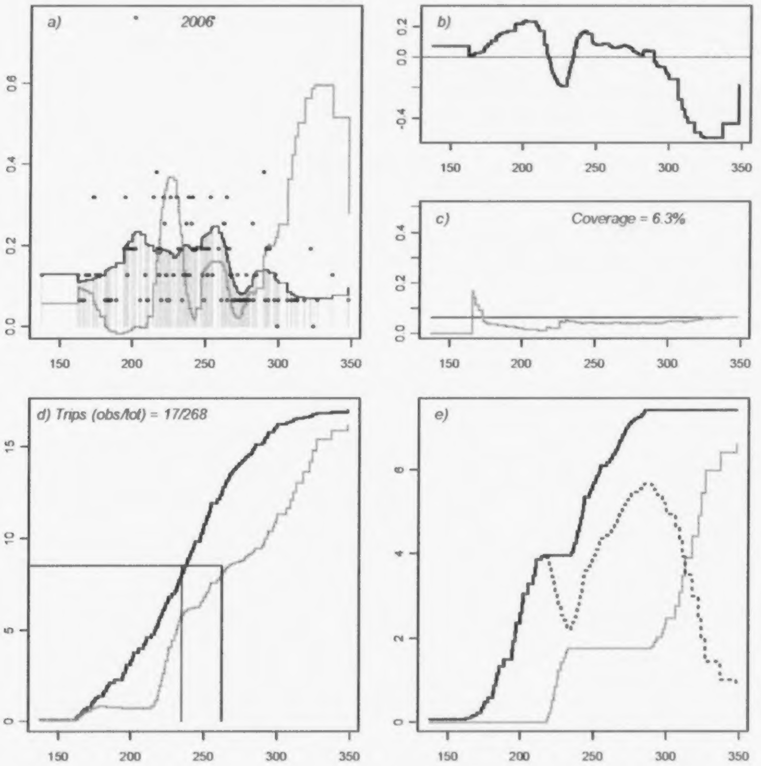
Figure 15. Plots of a) the loess smoothed observed sets (red) relative to optimally sampled fleet sets (black) by day of year, b) the difference between the optimum and reality, c) the running proportion of optimally sampled sets (black) and observed sets (red) relative to the cumulative total, d) the cumulative number of observed sets (red) relative to the cumulative number of optimally sampled fleet sets (black) and e) the cumulative difference of the number of optimally sampled sets to reality (black, dotted), positive differences (black) and negative differences (red). See text for interpretation.

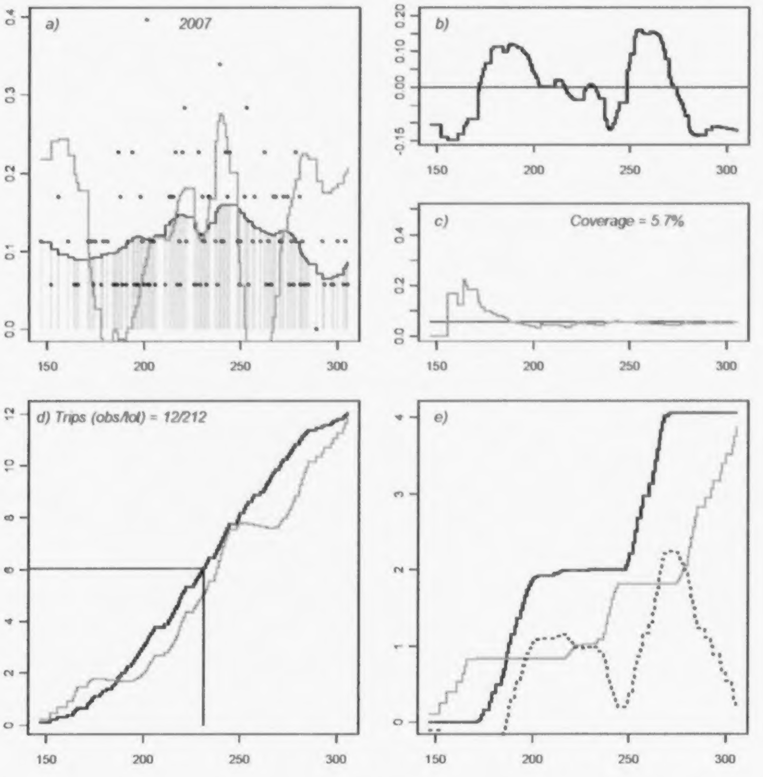

a)
2002
0.0
0.5
1.0
1.5
2.0
150
200
250
300
b)
0.2
-0.2
-0.6
c)
Coverage = 22.5%
0.0
0.2
0.4
d) Trips (obs/tot) = 48/213
0
10
20
30
40
e)
0
2
4
6
8
10

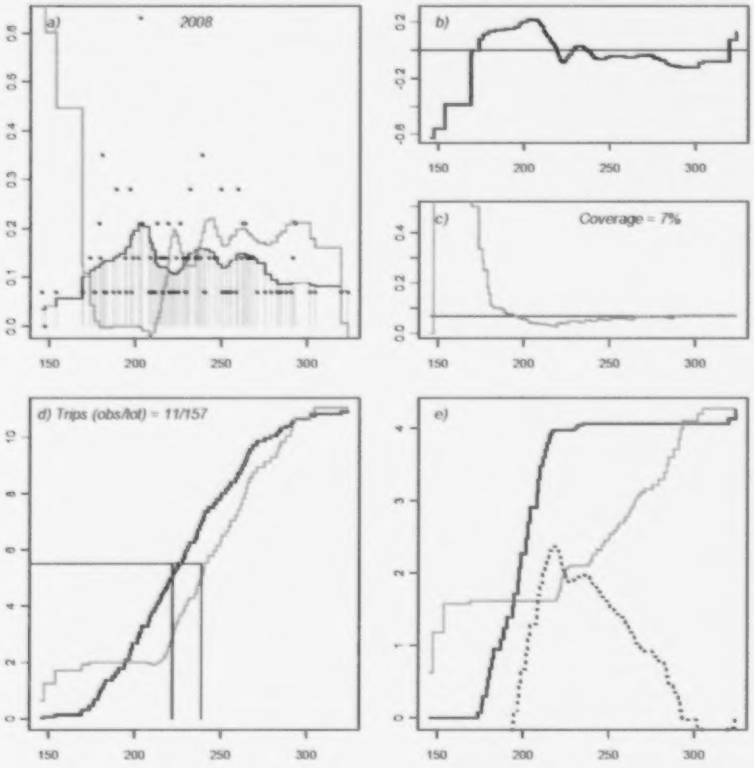

a)
2003
0.0
0.1
0.2
0.3
0.4
0.5
150
200
250
300
b)
0.2
-0.2
-0.6
c)
Coverage = 9.3%
0.0
0.2
0.4
d) Trips (obs/tot) = 18/194
0
5
10
15
e)
0
1
2
3
4
5

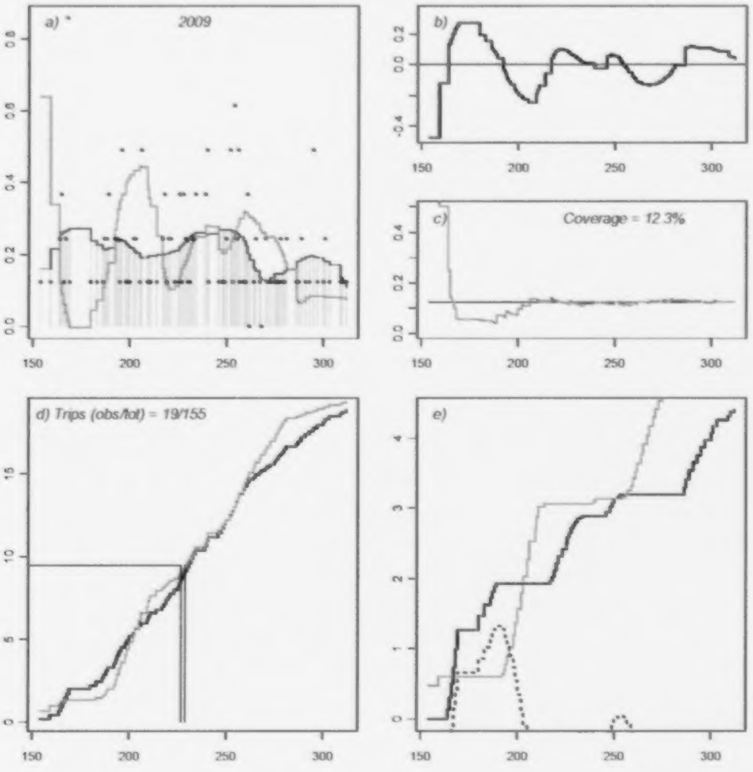

a)
2004
0.0
0.1
0.2
0.3
0.4
150
200
250
300
b)
0.0
-0.4
-0.8
c)
Coverage = 5%
0.0
0.2
0.4
d) Trips (obs/tot) = 12/239
0
2
4
6
8
10
12
e)
0
1
2
3
4
5


a)
2005
0.0
0.2
0.4
0.6
150
200
250
300
b)
-0.15
0.00
0.10
0.20
c)
Coverage = 5.3%
0.0
0.2
0.4
d) Trips (obs/tot) = 13/247
0
2
4
6
8
10
12
e)
0.0
0.5
1.0
1.5
2.0
2.5
3.0


a)
2006
b)
c)
Coverage = 6.3%
d) Trips (obs/tot) = 17/268
e)


a)
2007
b)
c)
Coverage = 5.7%
d) Trips (obs/tot) = 12/212
e)


a)
2008
0.0
0.1
0.2
0.3
0.4
0.5
0.6
150
200
250
300
b)
-0.6
-0.2
0.2
c)
Coverage = 7%
0.0
0.2
0.4
d) Trips (obs/tot) = 11/157
0
2
4
6
8
10
e)
0
1
2
3
4


a)
2009
0.0
0.2
0.4
0.6
0.8
150
200
250
300
b)
-0.4
0.0
0.2
c)
Coverage = 12.3%
0.0
0.2
0.4
d) Trips (obs/tot) = 19/155
0
5
10
15
e)
0
1
2
3
4

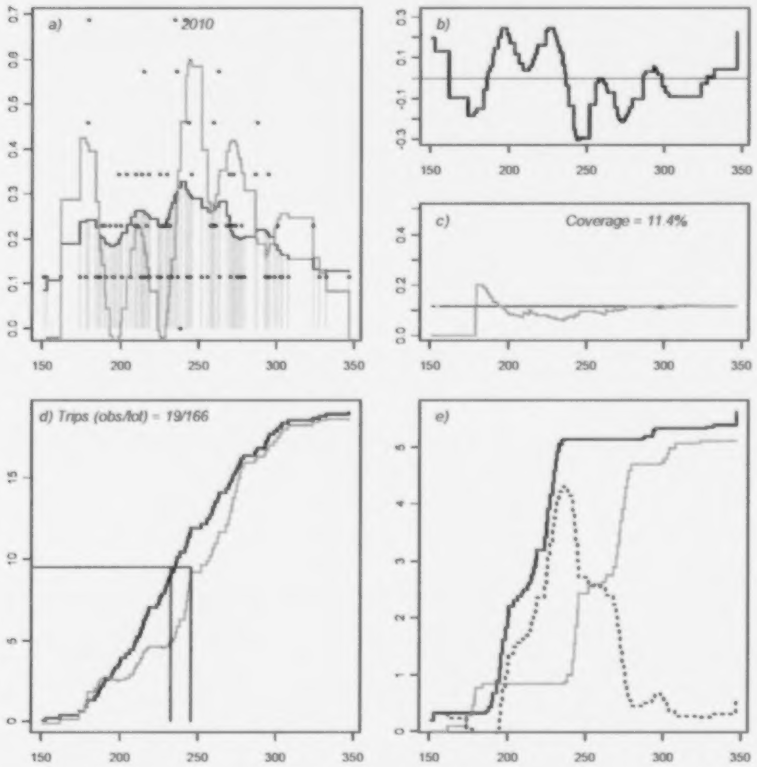
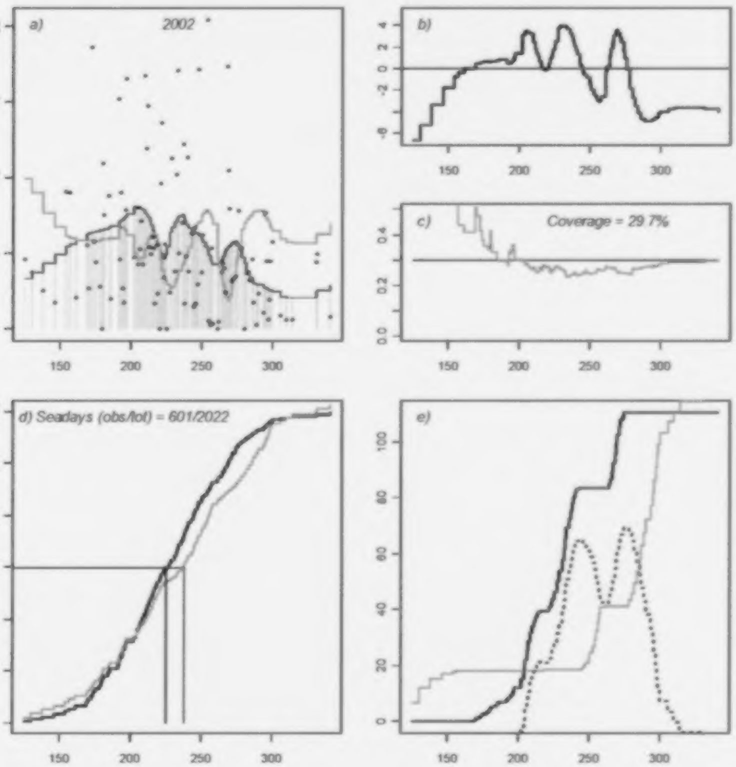
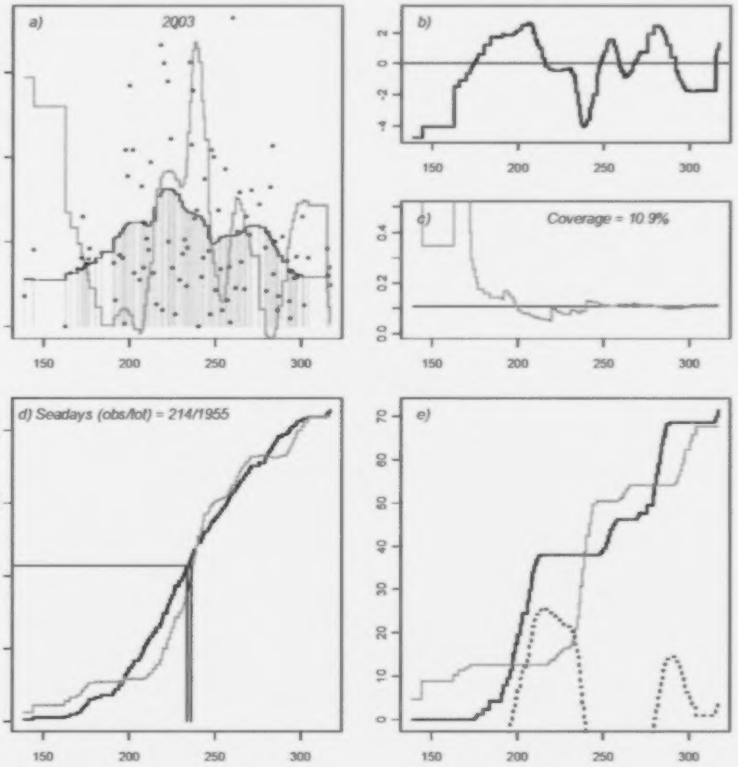
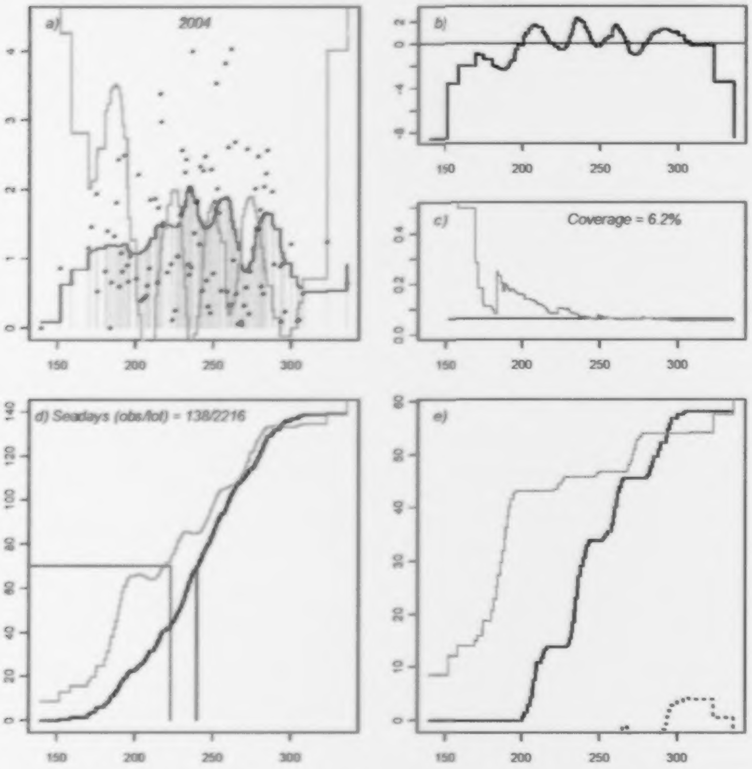
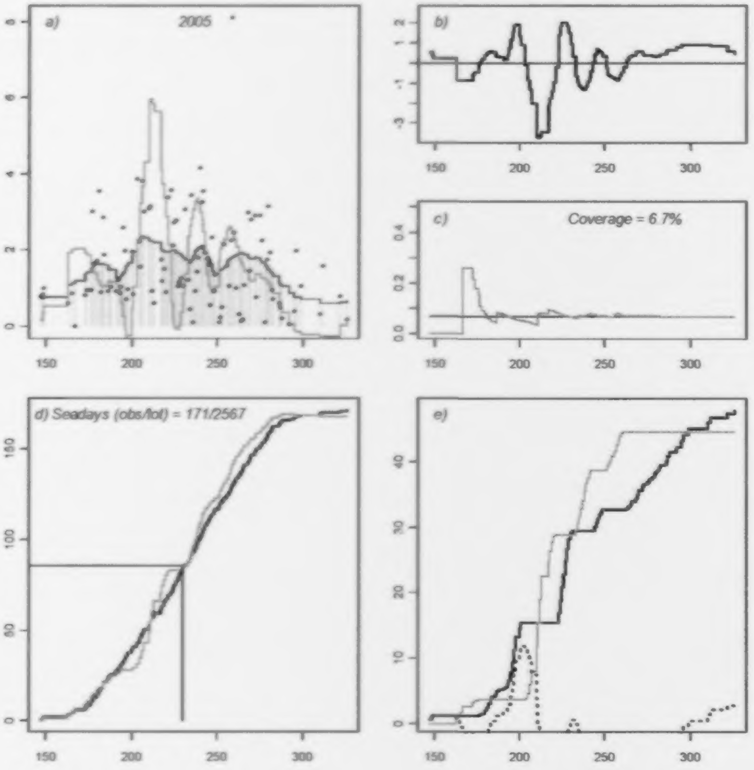


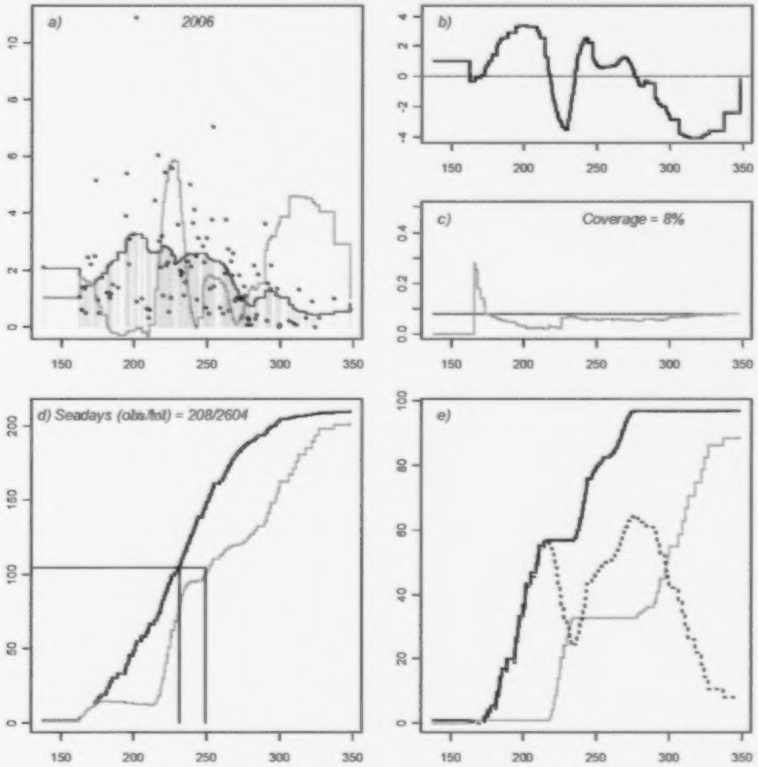
Figure 16. Plots of a) the loess smoothed observed trips (red) relative to optimally sampled fleet trips (black) by day of year, b) the difference between the optimum and reality, c) the running proportion of optimally sampled sets (black) and observed sets (red) relative to the cumulative total, d) the cumulative number of observed sets (red) relative to the cumulative number of optimally sampled fleet trips (black) and e) the cumulative difference of the number of optimally sampled trips to reality (black, dotted), positive differences (black) and negative differences (red). See text for interpretation.

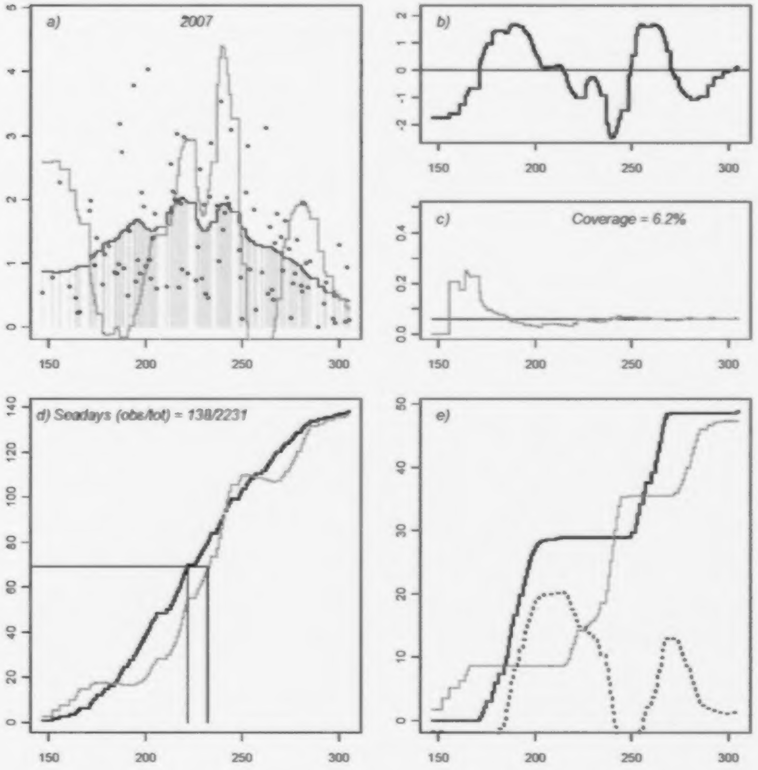

a)
2002
0
5
10
15
20
150
200
250
300
b)
-6
-2
0
2
4
c)
Coverage = 29.7%
0.0
0.2
0.4
d) Seadays (obs/tot) = 601/2022
0
100
200
300
400
500
600
e)
0
20
40
60
80
100

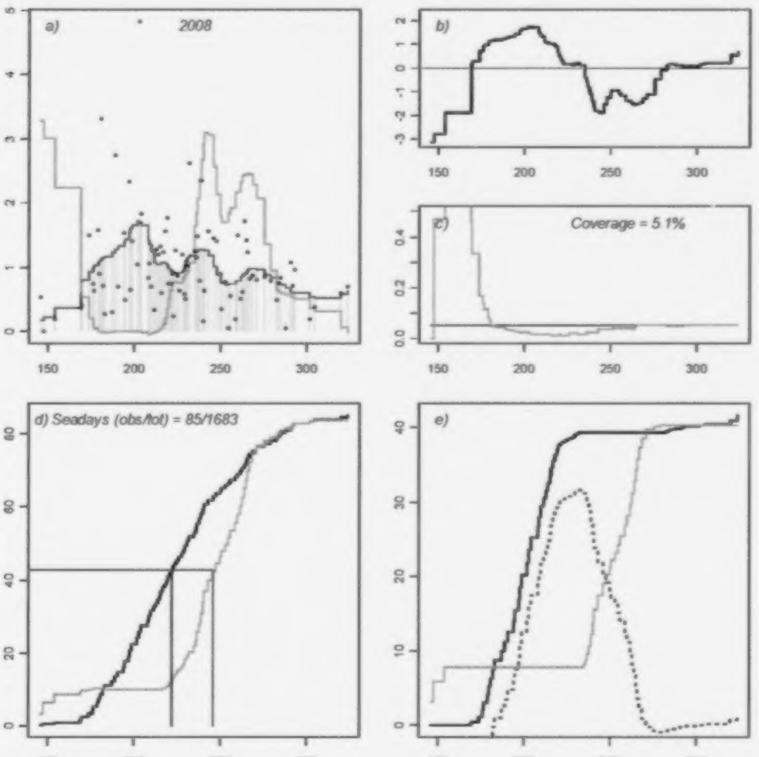

a)
2003
0
2
4
6
150
200
250
300
b)
-4
-2
0
2
c)
Coverage = 10.9%
0.0
0.2
0.4
d) Seadays (obs/tot) = 214/1955
0
50
100
150
200
e)
0
10
20
30
40
50
60
70

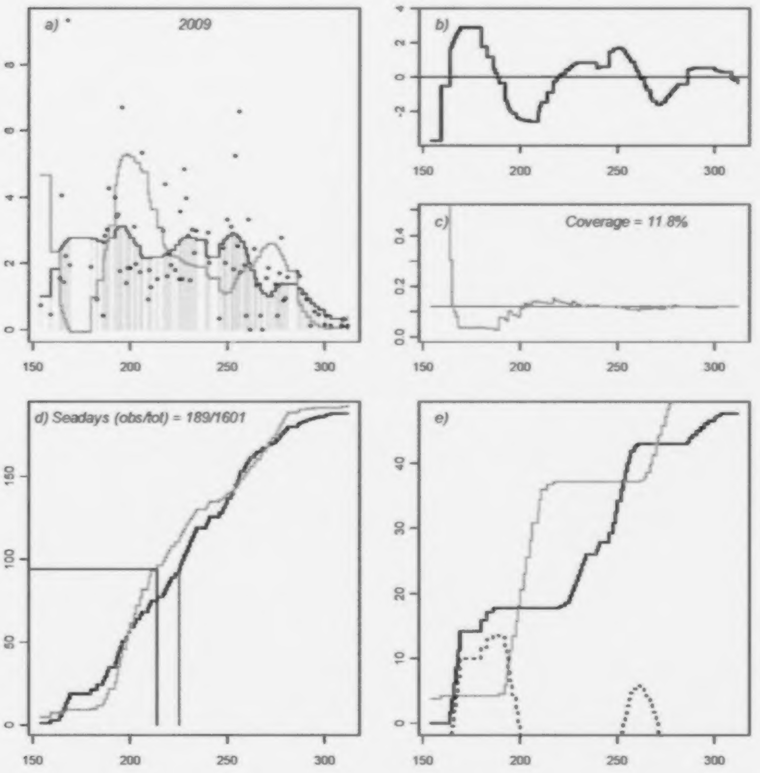

a)
2004
0
1
2
3
4
150
200
250
300
b)
2
0
-4
-8
150
200
250
300
c)
Coverage = 6.2%
0.0
0.2
0.4
150
200
250
300
d) Seadays (obs/tot) = 138/2216
0
20
40
60
80
100
120
140
150
200
250
300
e)
0
10
20
30
40
50
60
150
200
250
300


a)
2005
0
2
4
6
8
150
200
250
300
b)
2
1
-1
-3
150
200
250
300
c)
Coverage = 6.7%
0.0
0.2
0.4
150
200
250
300
d) Seadays (obs/tot) = 171/2567
0
50
100
150
150
200
250
300
e)
0
10
20
30
40
150
200
250
300


a)
2006
b)
c)
Coverage = 8%
d) Seadays (obs/tot) = 208/2604
e)
150
200
250
300
350


a)
2007
b)
c)
Coverage = 6.2%
d) Seadays (obs/tot) = 138/2231
e)
150
200
250
300


a) 2008
0
1
2
3
4
5
150
200
250
300
b)
-3
-2
-1
0
1
2
c)
Coverage = 5.1%
0.0
0.2
0.4
d) Seadays (obs/tot) = 85/1683
0
20
40
60
80
e)
0
10
20
30
40


a) 2009
0
2
4
6
8
150
200
250
300
b)
-2
0
2
4
c)
Coverage = 11.8%
0.0
0.2
0.4
d) Seadays (obs/tot) = 189/1601
0
50
100
150
e)
0
10
20
30
40

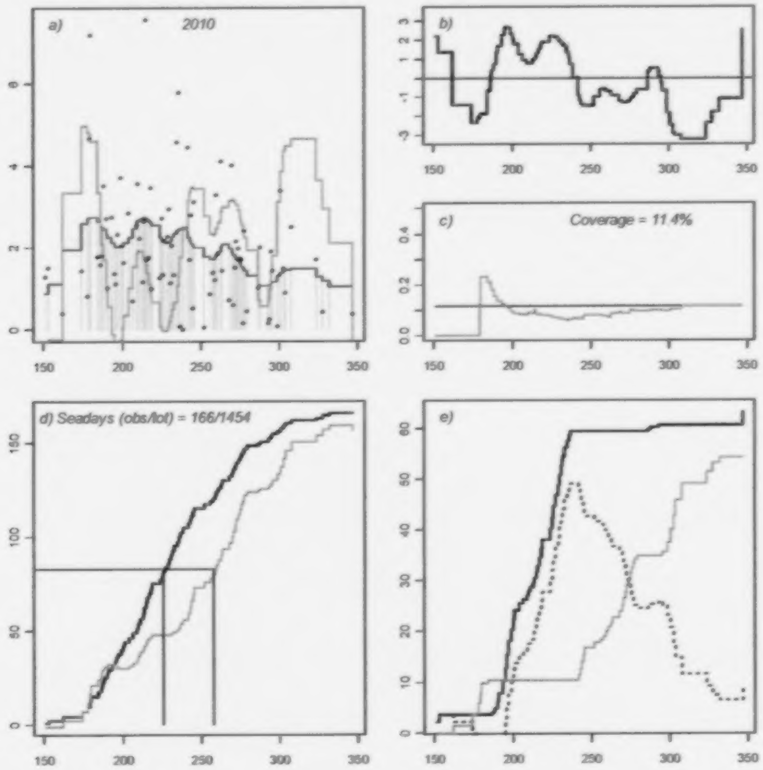


Figure 17. Plots of a) the loess smoothed observed sea days (red) relative to optimally sampled fleet sea days (black) by day of year, b) the difference between the optimum and reality, c) the running proportion of optimally sampled sea days (black) and observed sea days (red) relative to the cumulative total, d) the cumulative number of observed sea days (red) relative to the cumulative number of optimally sampled fleet sea days (black) and e) the cumulative difference of the number of optimally sampled sea days to reality (black, dotted), positive differences (black) and negative differences (red). See text for interpretation.

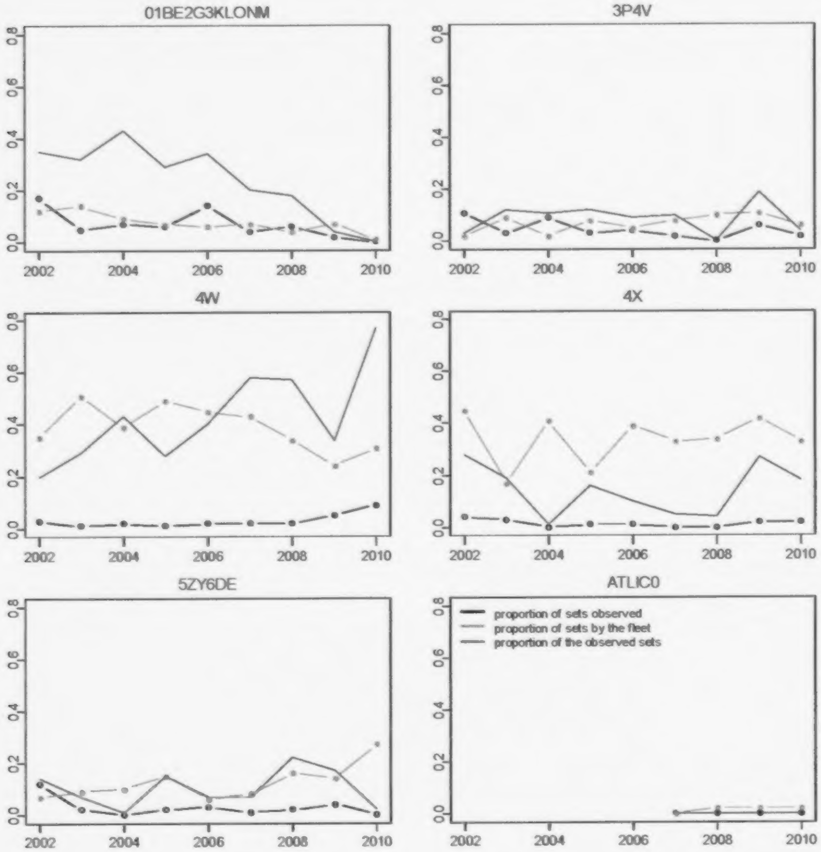
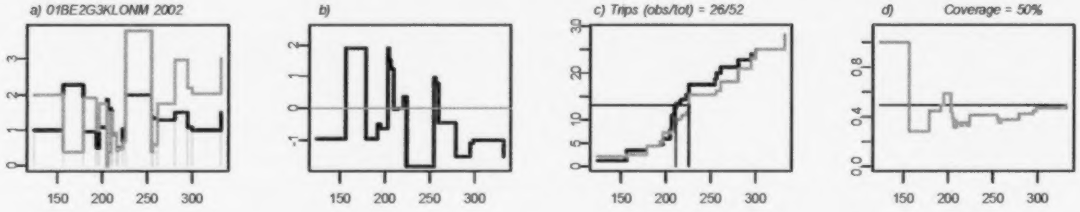
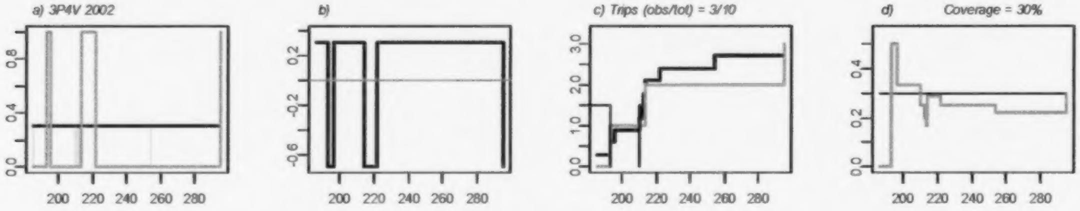
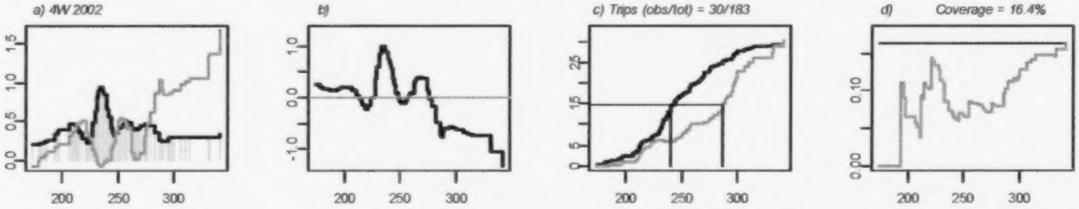
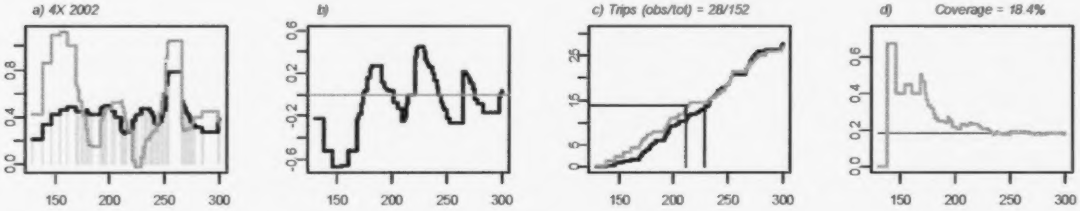


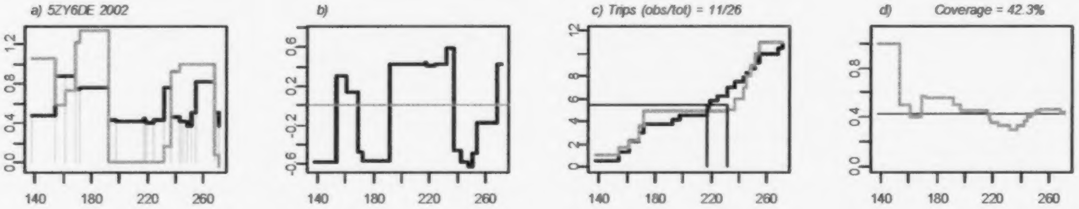
Figure 18. Fleet effort (proportion of sets) by area (red line, solid dot) is compared with observer effort by area (blue line, no dot). The coverage in each area is in black (hollow dot). The proportion of pelagic longline effort across all areas within a year (red and blue lines) should sum to one.

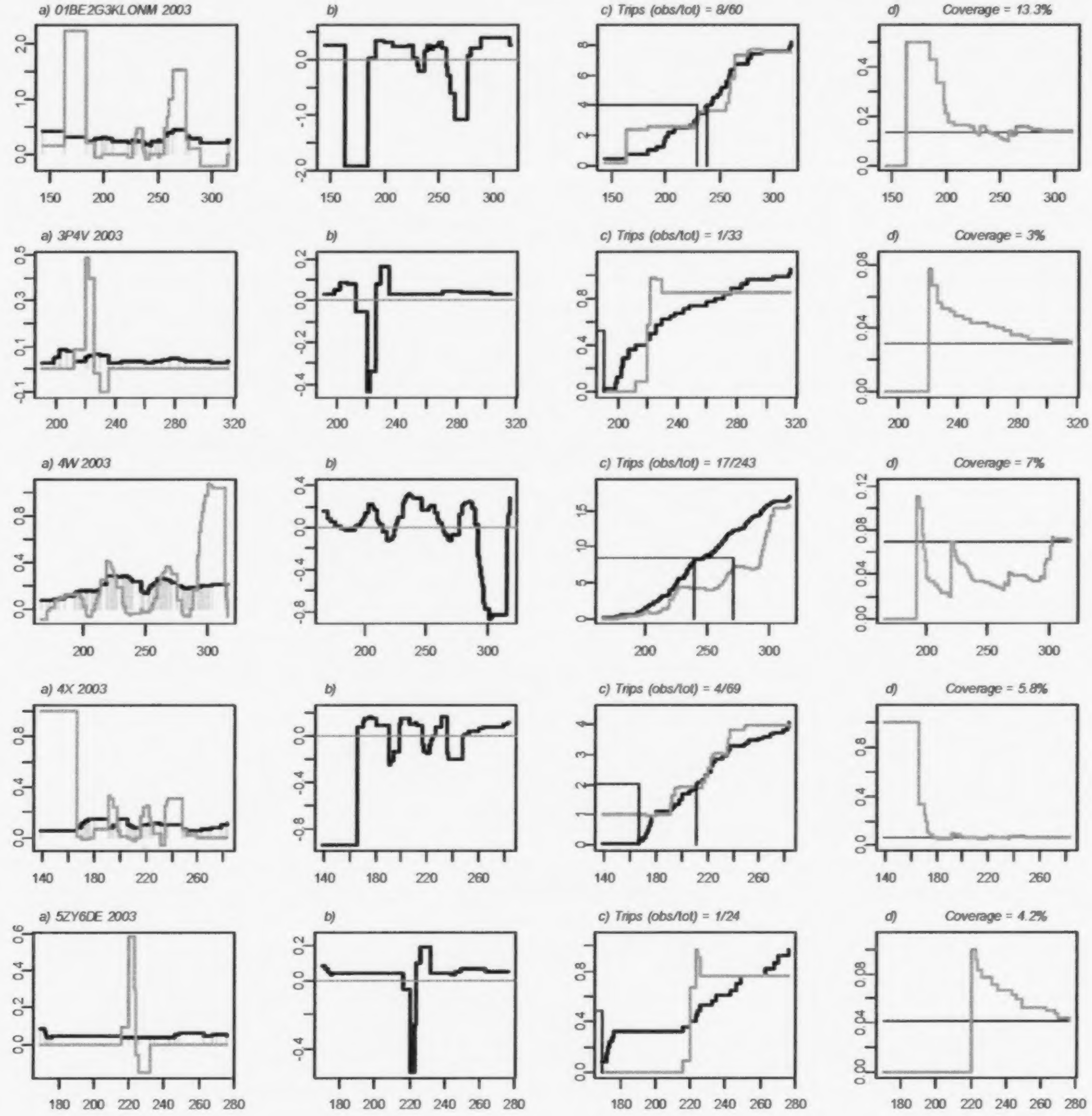

a) 01BE2G3KLONM 2002
b)
c) Trips (obs/tot) = 26/52
d) Coverage = 50%
150
200
250
300

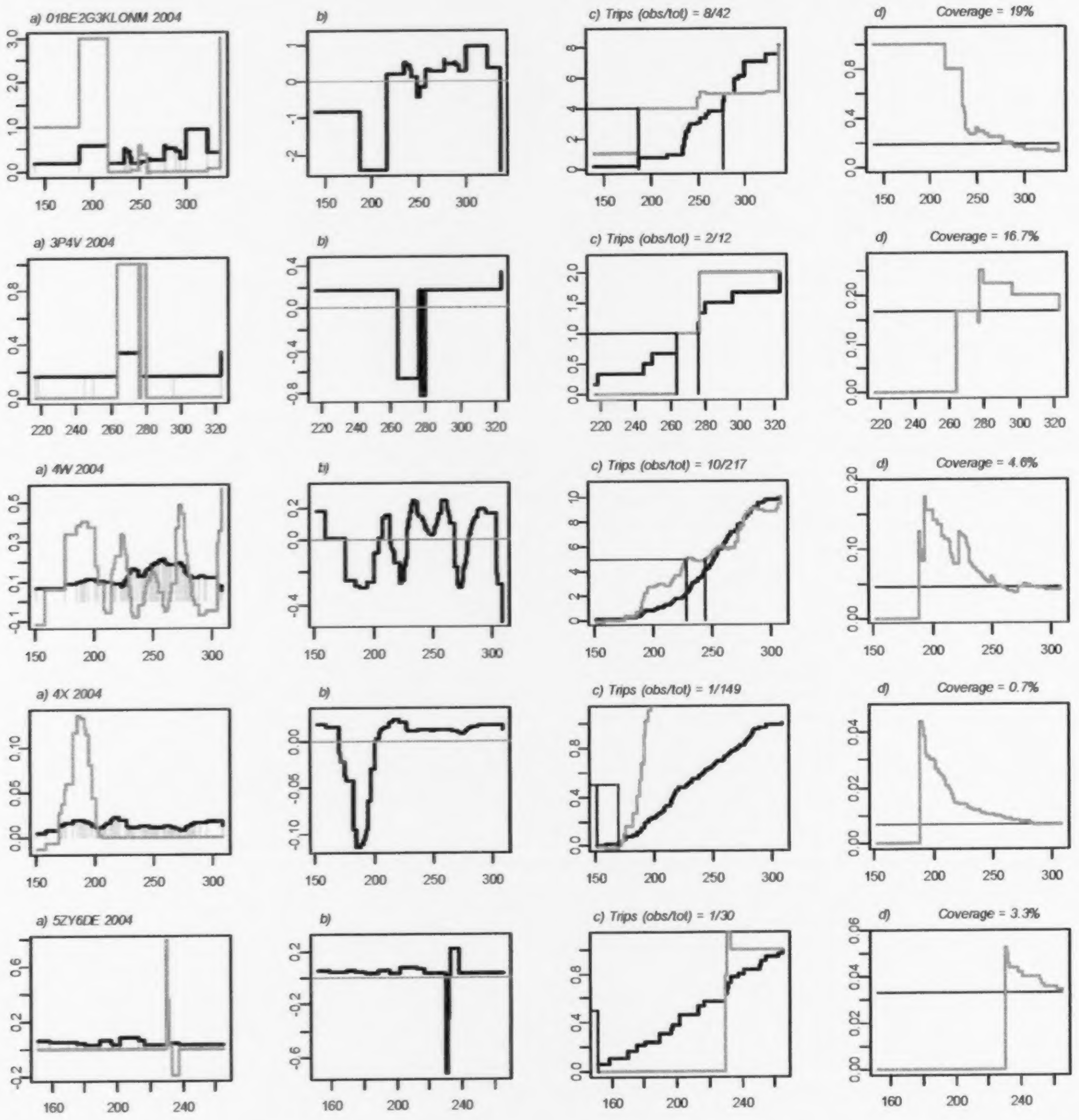

a) 3P4V 2002
b)
c) Trips (obs/tot) = 3/10
d) Coverage = 30%
200
220
240
260
280

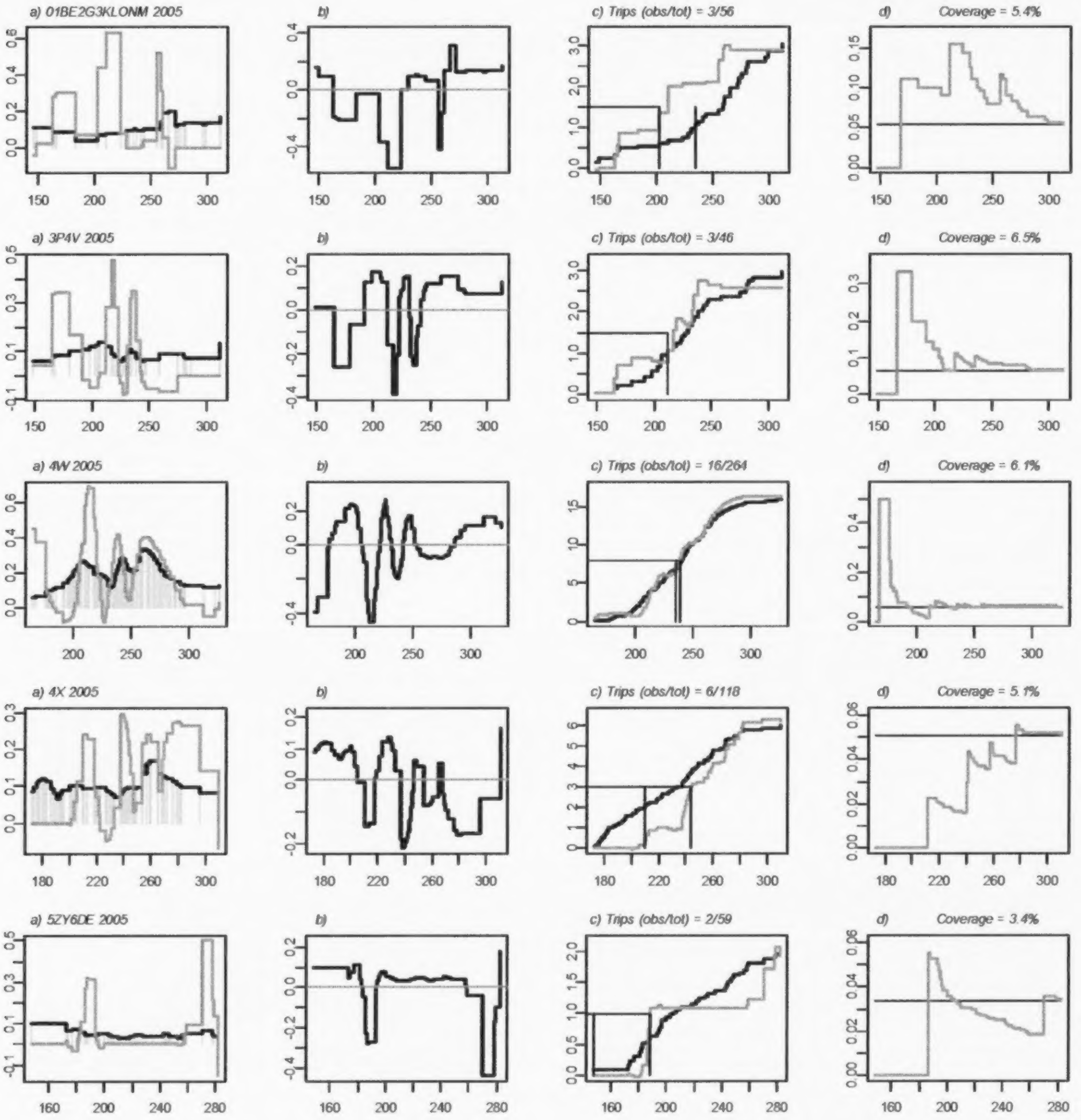

a) 4W 2002
b)
c) Trips (obs/tot) = 30/183
d) Coverage = 16.4%
200
250
300

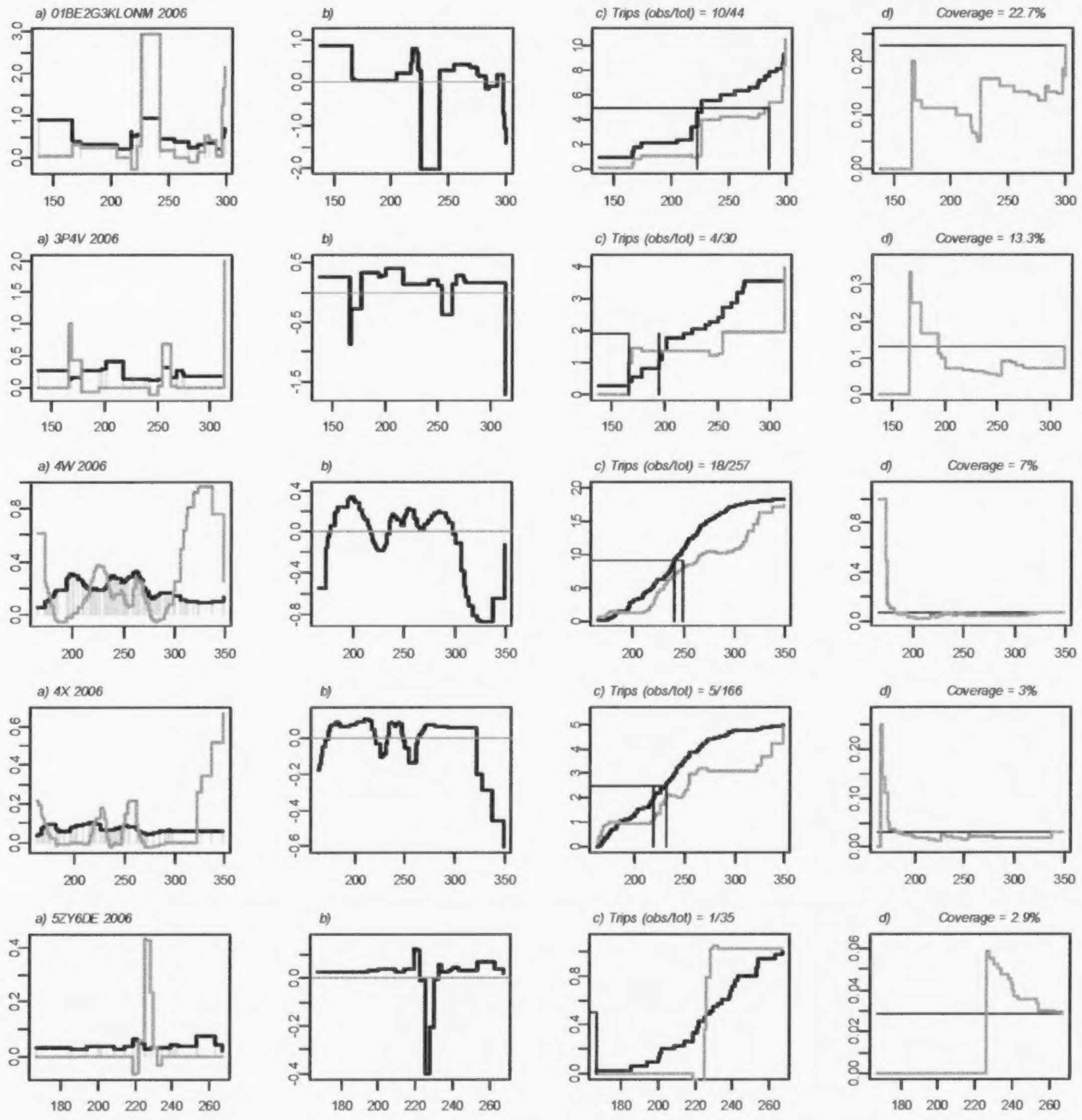

a) 4X 2002
b)
c) Trips (obs/tot) = 28/152
d) Coverage = 18.4%
150
200
250
300

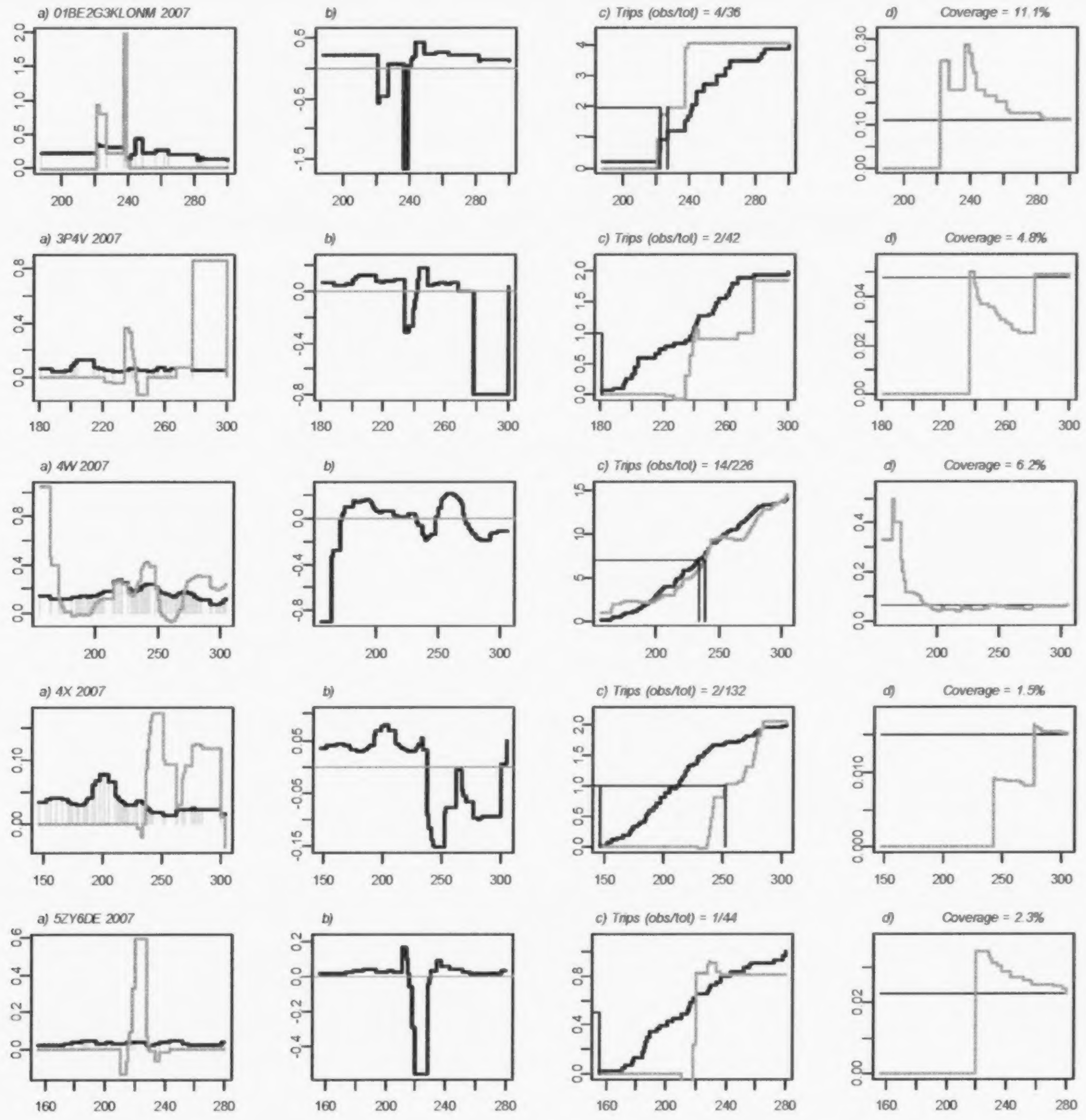

a) 5ZY6DE 2002
b)
c) Trips (obs/tot) = 11/26
d) Coverage = 42.3%
140
180
220
260

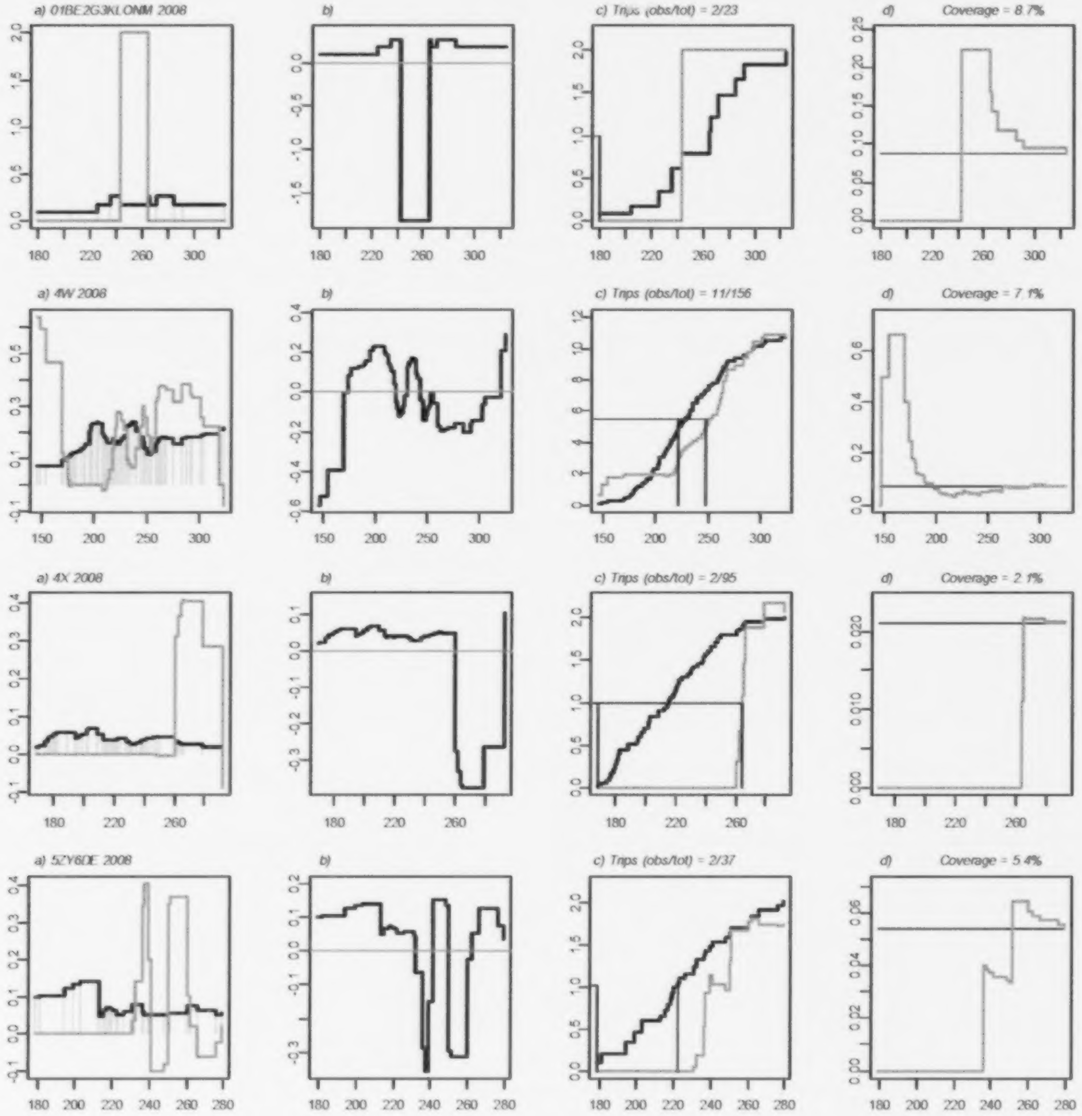

a) 01BE2G3KLONM 2003
b)
c) Trips (obs/tot) = 8/60
d) Coverage = 13.3%
a) 3P4V 2003
b)
c) Trips (obs/tot) = 1/33
d) Coverage = 3%
a) 4W 2003
b)
c) Trips (obs/tot) = 17/243
d) Coverage = 7%
a) 4X 2003
b)
c) Trips (obs/tot) = 4/69
d) Coverage = 5.8%
a) 5ZY6DE 2003
b)
c) Trips (obs/tot) = 1/24
d) Coverage = 4.2%

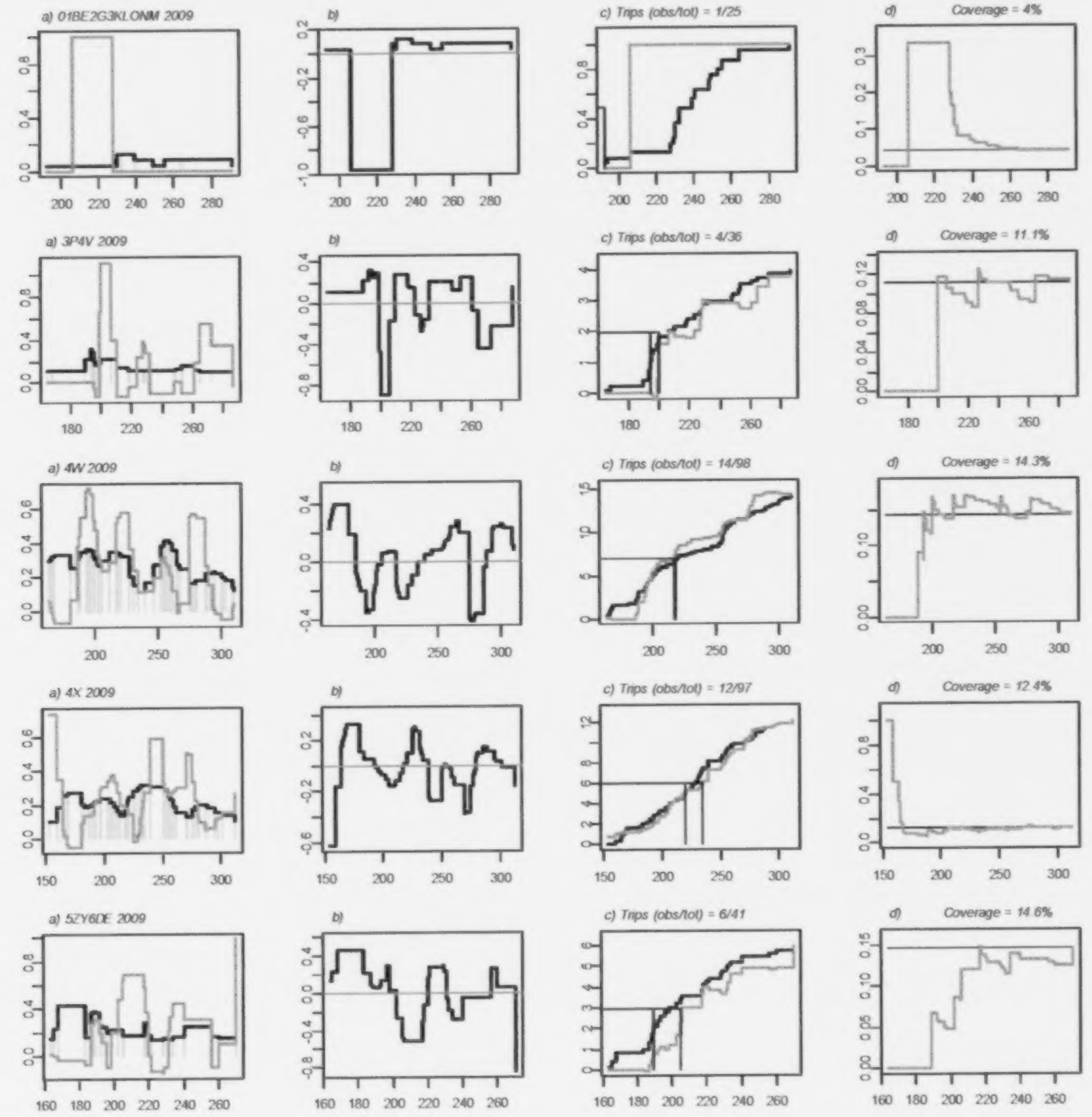

a) 01BE2G3KLONM 2004
0.0
1.0
2.0
3.0
150
200
250
300
b)
-2
-1
0
1
c) Trips (obs/tot) = 8/42
0
2
4
6
8
d)
Coverage = 19%
0.0
0.4
0.8
a) 3P4V 2004
0.0
0.4
0.8
220
240
260
280
300
320
b)
-0.8
-0.4
0.0
0.4
c) Trips (obs/tot) = 2/12
0.0
0.5
1.0
1.5
2.0
d)
Coverage = 16.7%
0.00
0.10
0.20
a) 4W 2004
-0.1
0.1
0.3
0.5
150
200
250
300
b)
-0.4
0.0
0.2
c) Trips (obs/tot) = 10/217
0
2
4
6
8
10
d)
Coverage = 4.6%
0.00
0.10
0.20
a) 4X 2004
0.00
0.05
0.10
b)
-0.10
-0.05
0.00
c) Trips (obs/tot) = 1/149
0.0
0.4
0.8
d)
Coverage = 0.7%
0.00
0.02
0.04
a) 5ZY6DE 2004
-0.2
0.2
0.6
160
200
240
b)
-0.6
-0.2
0.2
c) Trips (obs/tot) = 1/30
0.0
0.4
0.8
d)
Coverage = 3.3%
0.00
0.02
0.04
0.06


a) 01BE2G3KLONM 2005
b)
c) Trips (obs/tot) = 3/56
d) Coverage = 5.4%
a) 3P4V 2005
b)
c) Trips (obs/tot) = 3/46
d) Coverage = 6.5%
a) 4W 2005
b)
c) Trips (obs/tot) = 16/264
d) Coverage = 6.1%
a) 4X 2005
b)
c) Trips (obs/tot) = 6/118
d) Coverage = 5.1%
a) 5ZY6DE 2005
b)
c) Trips (obs/tot) = 2/59
d) Coverage = 3.4%


a) 01BE2G3KLONM 2006
b)
c) Trips (obs/tot) = 10/44
d) Coverage = 22.7%
a) 3P4V 2006
b)
c) Trips (obs/tot) = 4/30
d) Coverage = 13.3%
a) 4W 2006
b)
c) Trips (obs/tot) = 18/257
d) Coverage = 7%
a) 4X 2006
b)
c) Trips (obs/tot) = 5/166
d) Coverage = 3%
a) 5ZY6DE 2006
b)
c) Trips (obs/tot) = 1/35
d) Coverage = 2.9%
150
200
250
300
350
180
220
240
260


a) 01BE2G3KLONM 2007
b)
c) Trips (obs/tot) = 4/36
d) Coverage = 11.1%
a) 3P4V 2007
b)
c) Trips (obs/tot) = 2/42
d) Coverage = 4.8%
a) 4W 2007
b)
c) Trips (obs/tot) = 14/226
d) Coverage = 6.2%
a) 4X 2007
b)
c) Trips (obs/tot) = 2/132
d) Coverage = 1.5%
a) 5ZY6DE 2007
b)
c) Trips (obs/tot) = 1/44
d) Coverage = 2.3%


a) 01BE2G3KLONM 2008
b)
c) Trips (obs/tot) = 2/23
d) Coverage = 8.7%
a) 4W 2008
b)
c) Trips (obs/tot) = 11/156
d) Coverage = 7.1%
a) 4X 2008
b)
c) Trips (obs/tot) = 2/95
d) Coverage = 2.1%
a) 5ZY6DE 2008
b)
c) Trips (obs/tot) = 2/37
d) Coverage = 5.4%


a) 01BE2G3KLONM 2009
b)
c) Trips (obs/tot) = 1/25
d) Coverage = 4%
a) 3P4V 2009
b)
c) Trips (obs/tot) = 4/36
d) Coverage = 11.1%
a) 4W 2009
b)
c) Trips (obs/tot) = 14/98
d) Coverage = 14.3%
a) 4X 2009
b)
c) Trips (obs/tot) = 12/97
d) Coverage = 12.4%
a) 5ZY6DE 2009
b)
c) Trips (obs/tot) = 6/41
d) Coverage = 14.6%

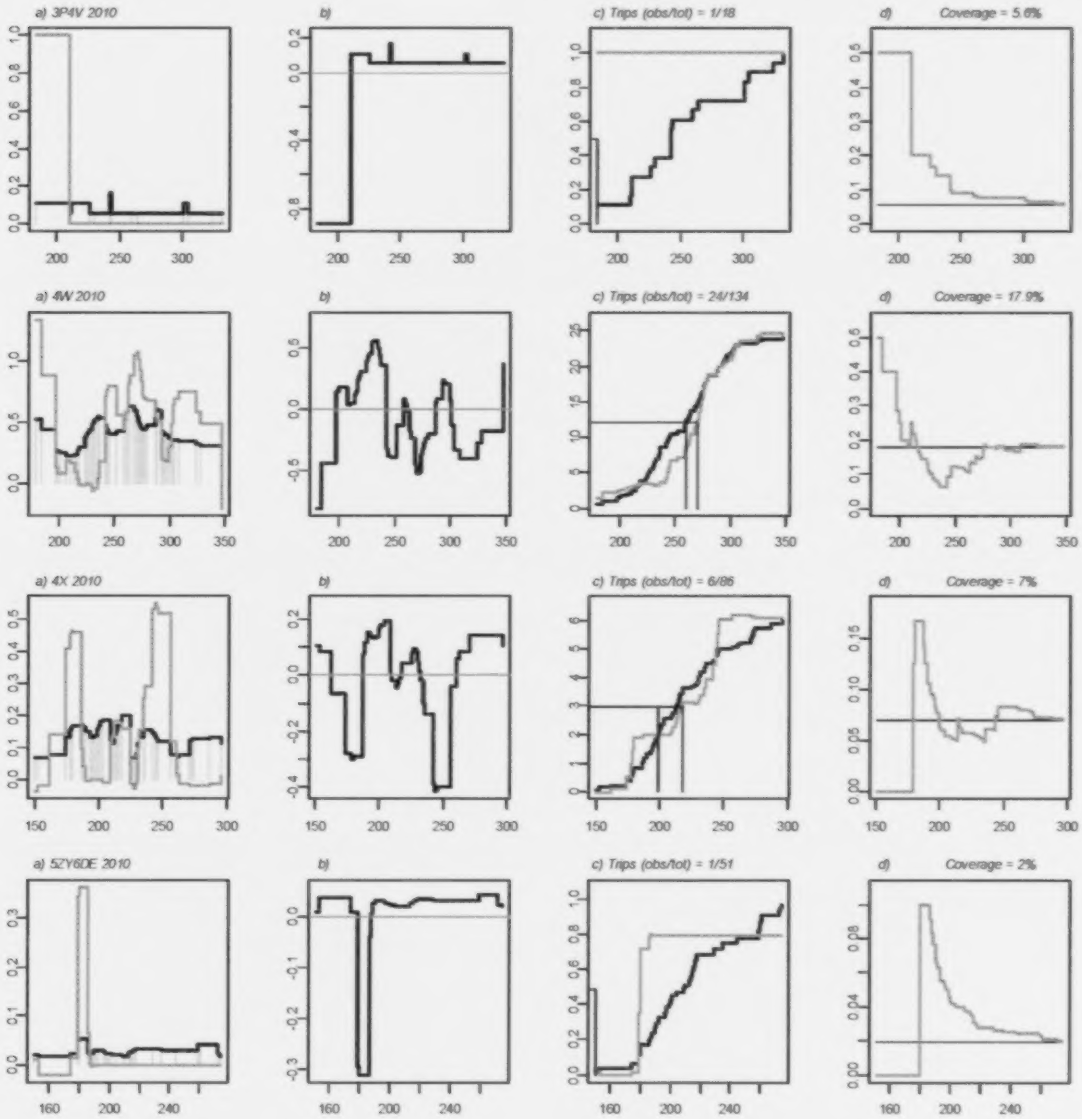


Figure 19. Plots of a) the loess smoothed observed sea days (red) relative to optimally sampled fleet sea days (black) by day of year and area, b) the difference between the optimum and reality, c) the cumulative number of observed sea days (red) relative to the cumulative number of optimally sampled fleet sea days (black) and d) the running proportion of optimally sampled sea days (black) and observed sea days (red) relative to the cumulative total. See text for interpretation.

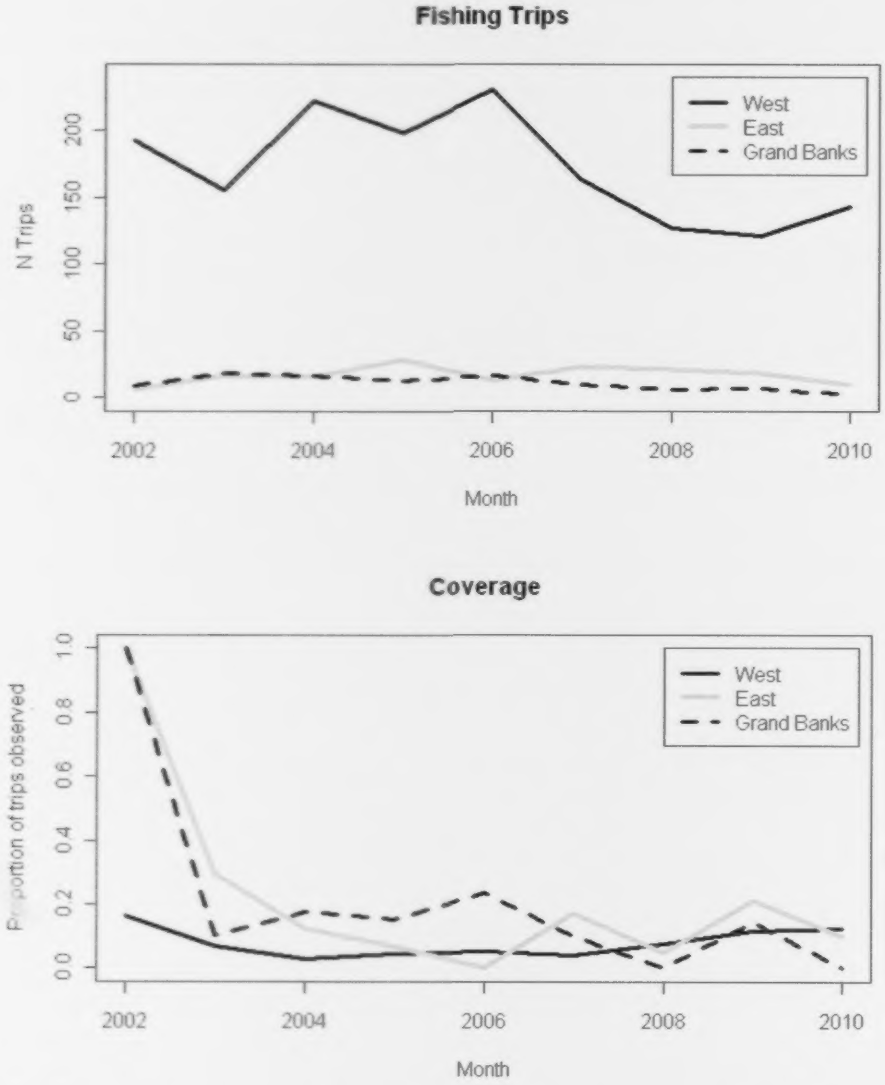


Figure 20. Total pelagic longline fishing trips (upper) and annual percent observer coverage based on trips (lower) for areas East of 60°, West of 60° and the Grand Banks.

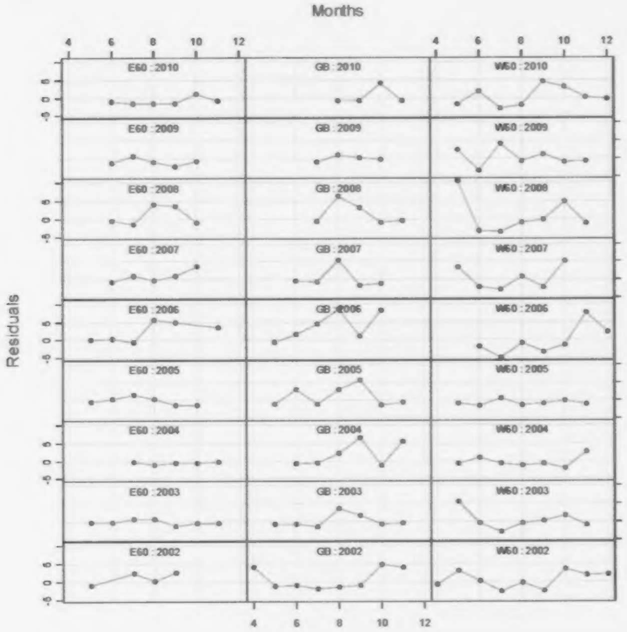


Figure 21. The Pearson residuals from the goodness-of-fit of the observed set count in each month and area to the expected count assuming sampling was a constant proportion of the fishing. The test was repeated for each year. The areas were E60, W60 (east and west of 60°W longitude) and GB (Grand Banks).

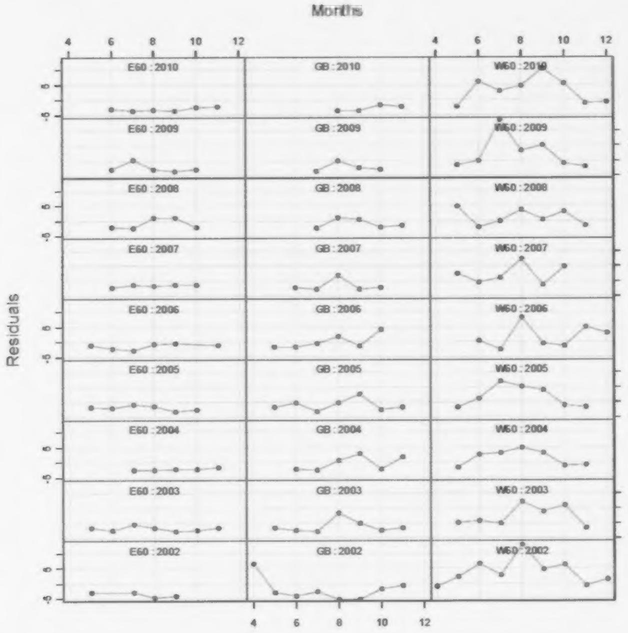


Figure 22. The Pearson residuals from the goodness-of-fit of the observed set count in each month and area to the expected count assuming sampling was conducted according to science advice. The test was repeated for each year. The areas were E60, W60 (east and west of 60°W longitude) and GB (Grand Banks).

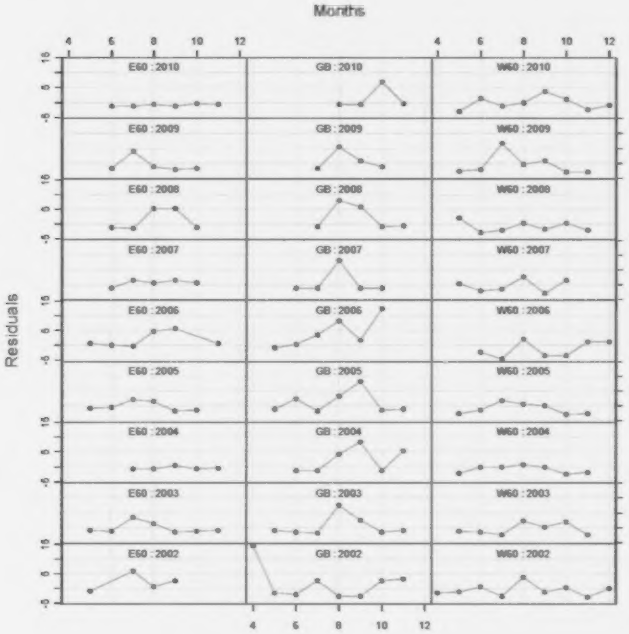


Figure 23. The Pearson residuals from the goodness-of-fit of the observed set count in each month and area to the expected count assuming sampling was conducted according to science advice but weighted by the proportion of fishing in each area. The test was repeated for each year. The areas were E60, W60 (east and west of 60°W longitude) and GB (Grand Banks).

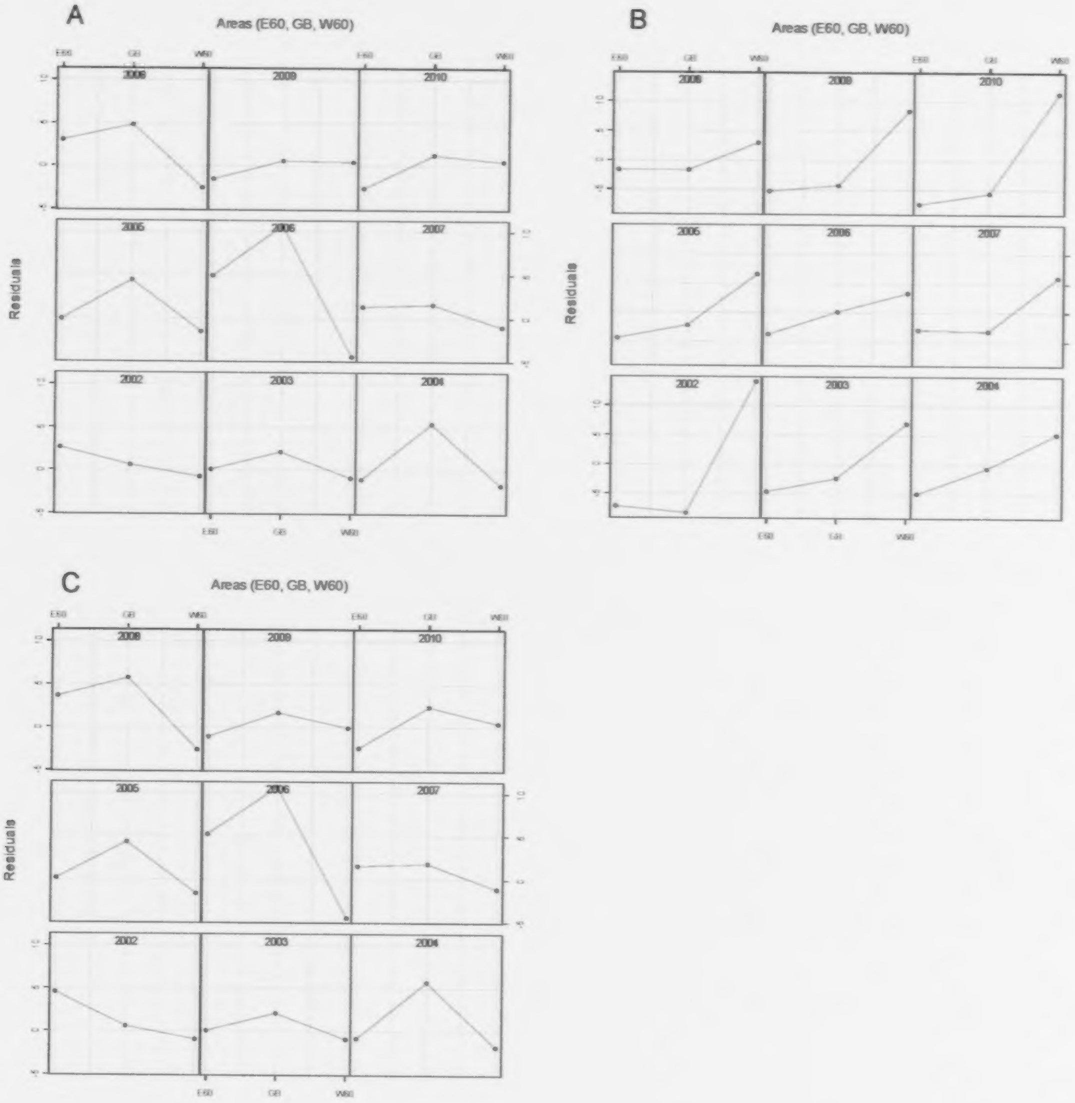


Figure 24. The Pearson residuals from the goodness-of-fit of the observed set count in each area to the expected count assuming sampling was A) a constant proportion of the fishing, B) conducted according to science advice and C) conducted according to science advice but weighted by the proportion of fishing in each area. The test was repeated for each year. The areas were E60, W60 (east and west of 60°W longitude) and GB (Grand Banks).

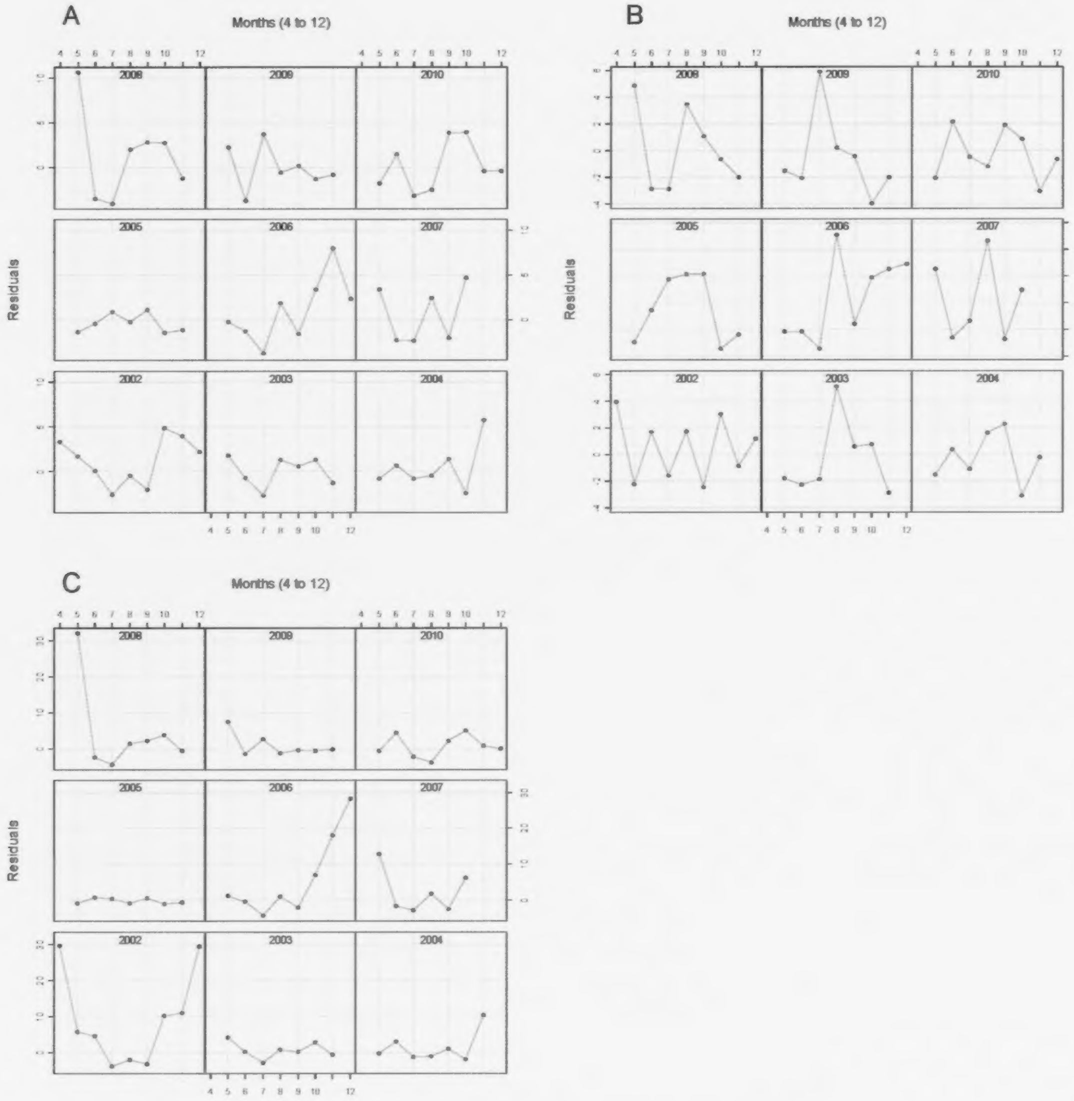


Figure 25. The Pearson residuals from the goodness-of-fit of the observed set count in each month to the expected count assuming sampling was A) a constant proportion of the fishing, B) conducted according to science advice and C) conducted according to science advice but weighted by the proportion of fishing in each area. The test was repeated for each year. The areas were E60, W60 (east and west of 60^oW longitude) and GB (Grand Banks).

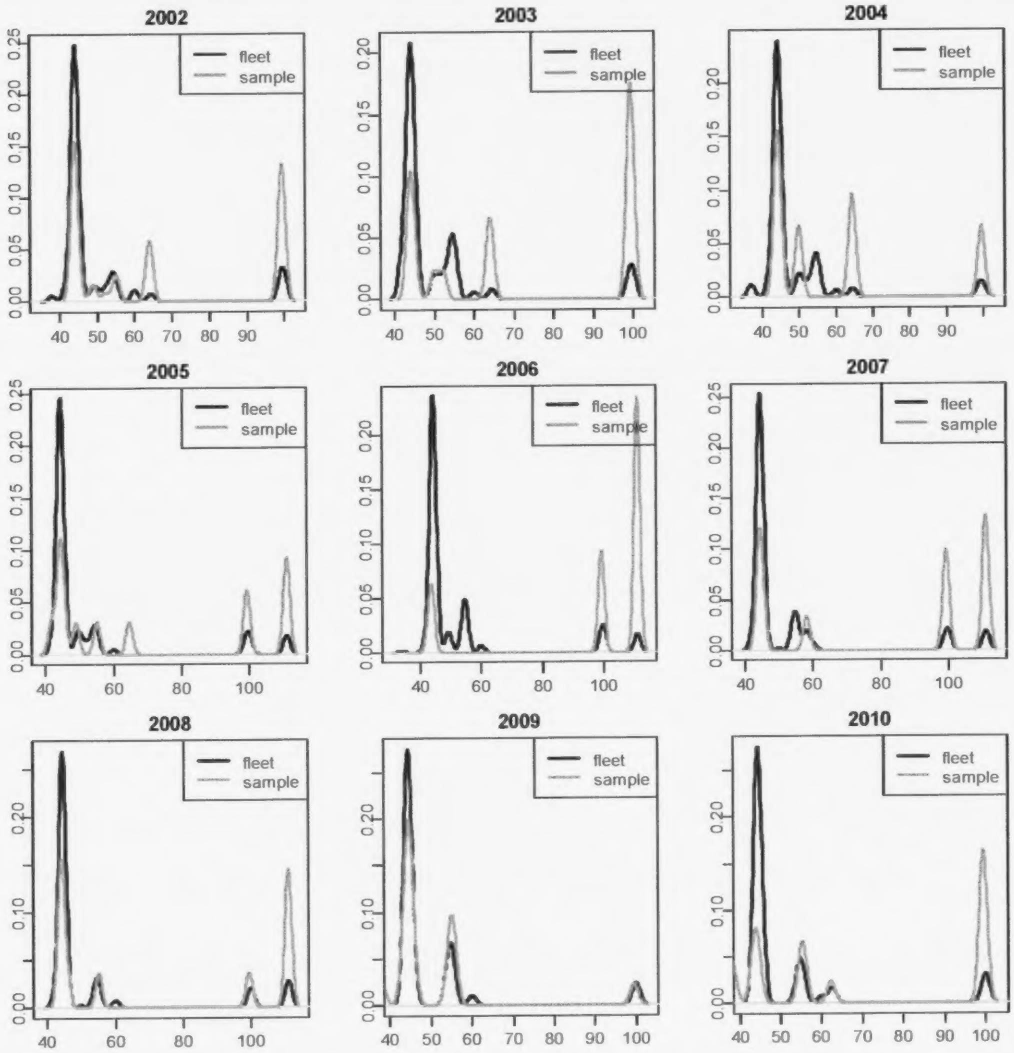


Figure 26. The frequency of occurrence of vessel lengths in the entire pelagic longline fleet (black) and the observed portion (red).

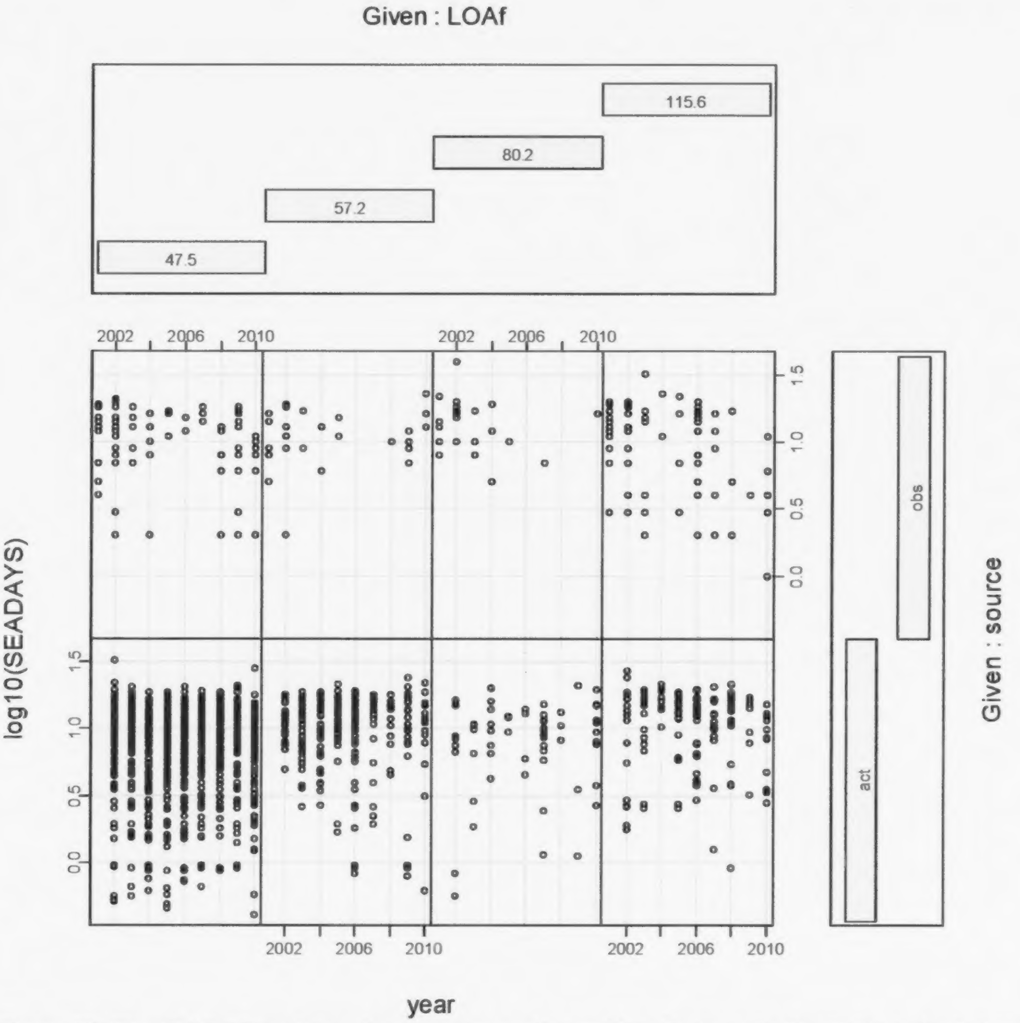


Figure 27. The distribution of sea days by year and vessel length class for the entire pelagic longline fleet (act) and the observed fraction (obs).

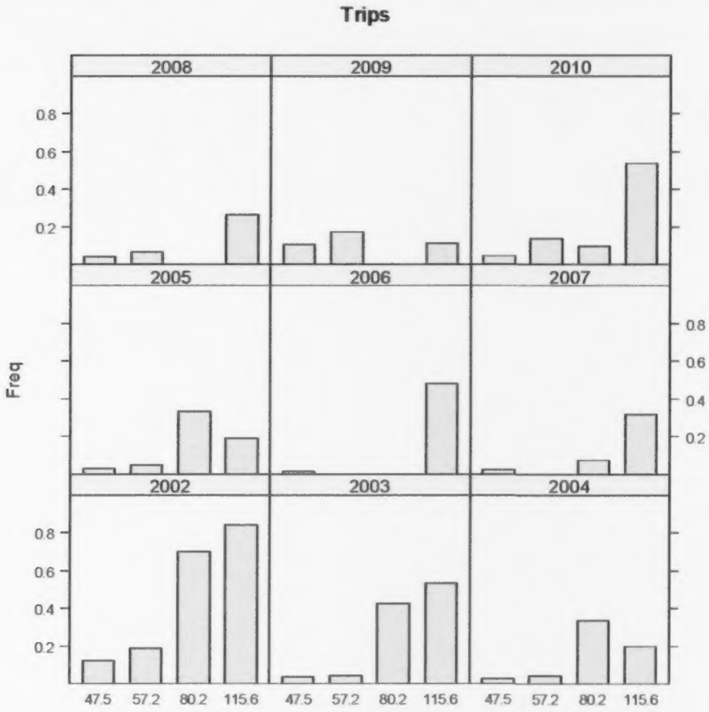


Figure 28. The proportion of trips observed by year and vessel length class for the pelagic longline fishery.

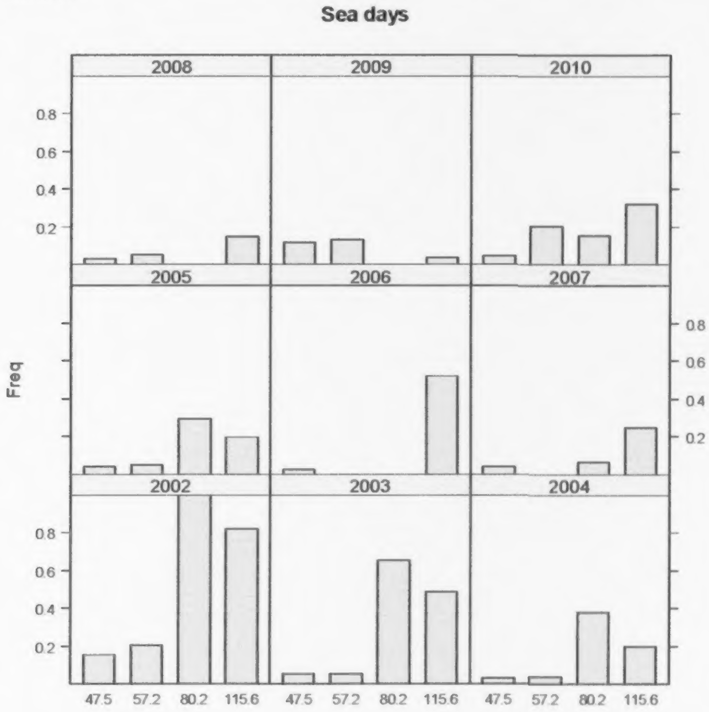


Figure 29. The proportion of sea days observed by year and vessel length class for the pelagic longline fishery.

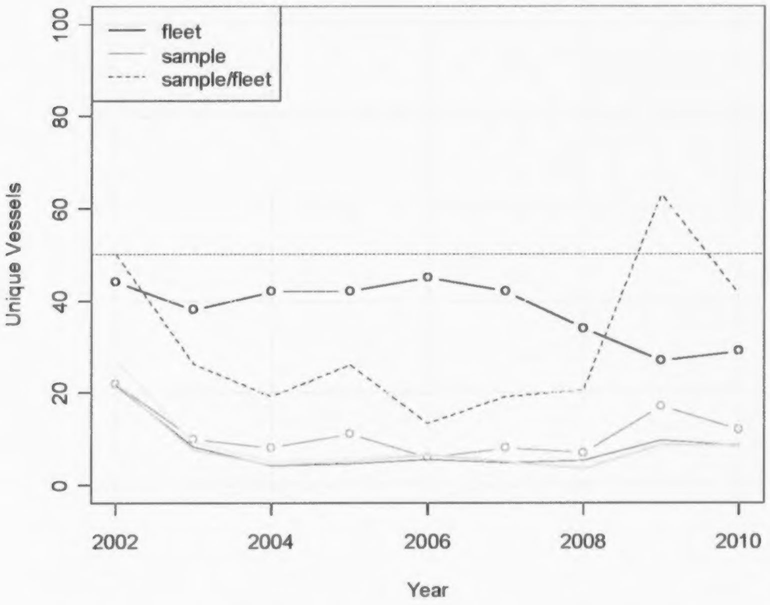


Figure 30. The number of unique vessels in the pelagic longline fishery by year (black) compared with the observed number (red), its ratio (blue dotted) and the proportion of coverage assessed using sea days, trips and sets (remaining lines).

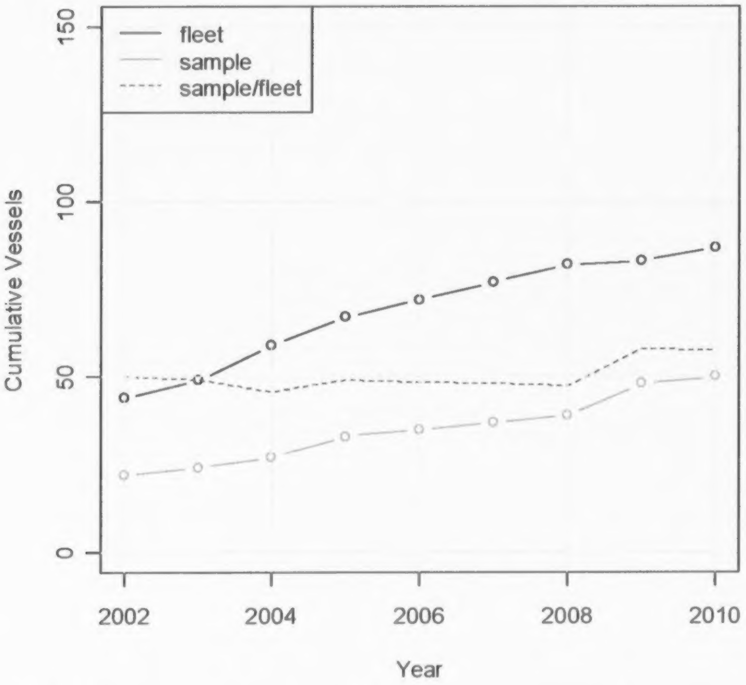
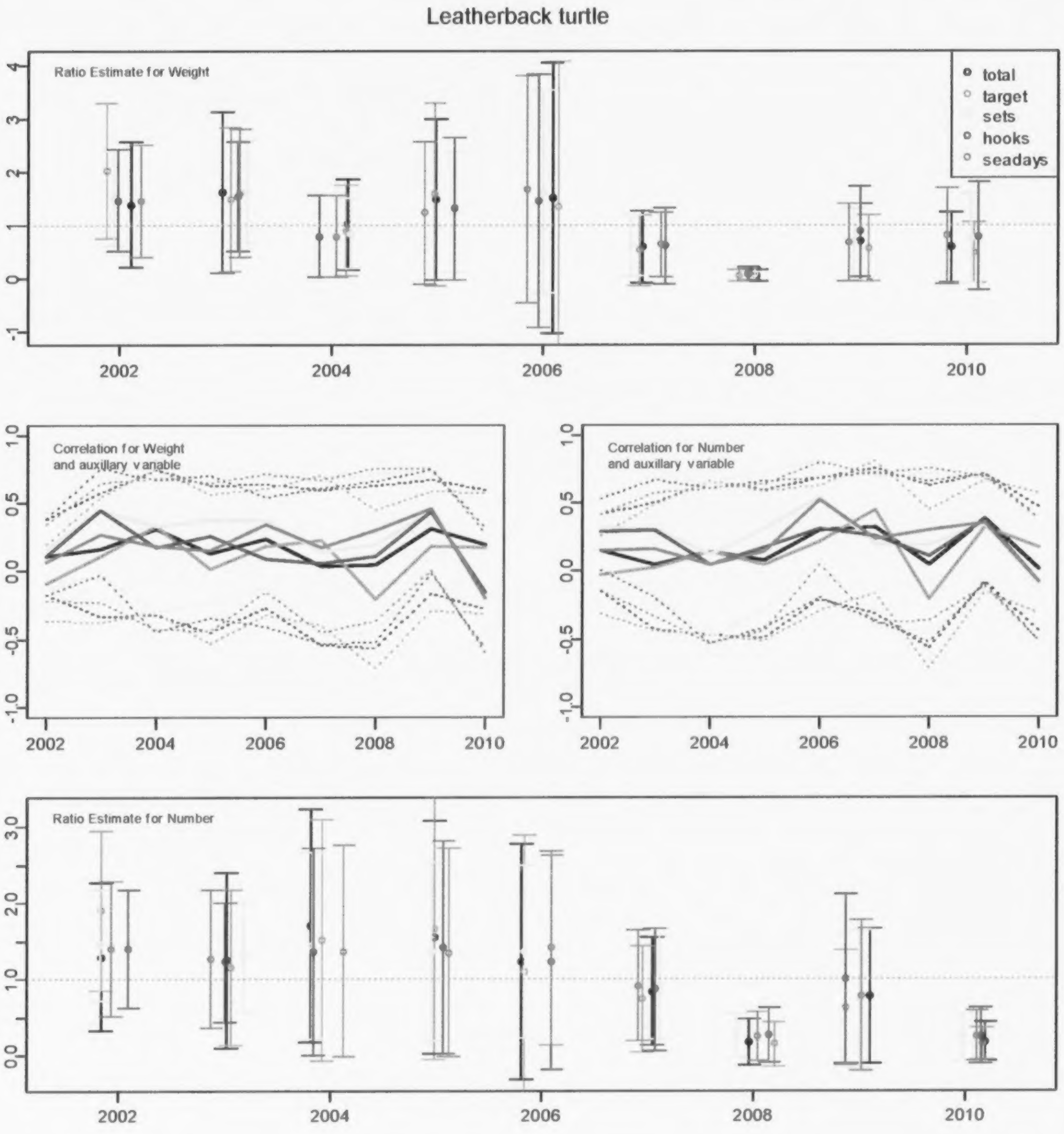
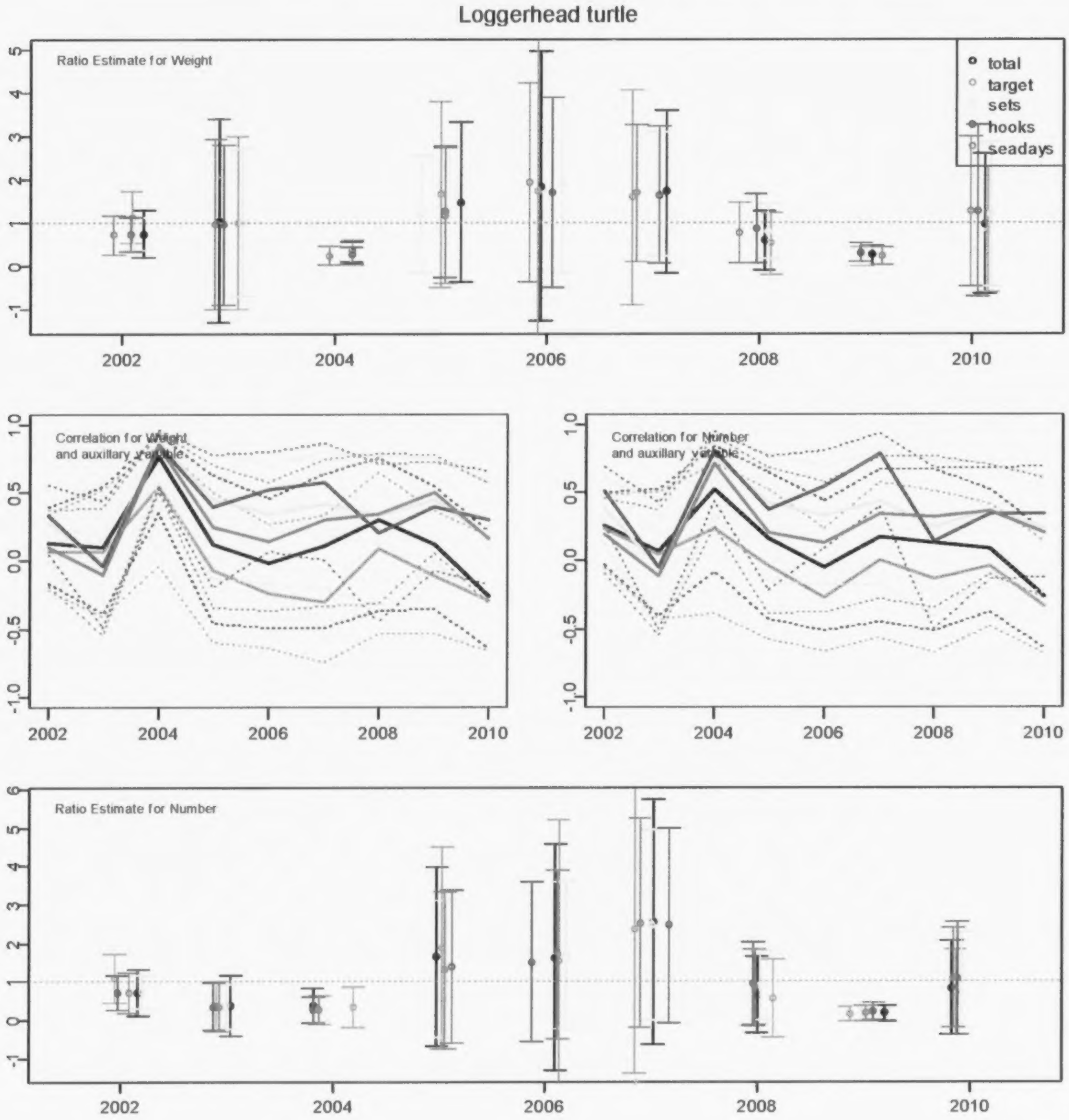
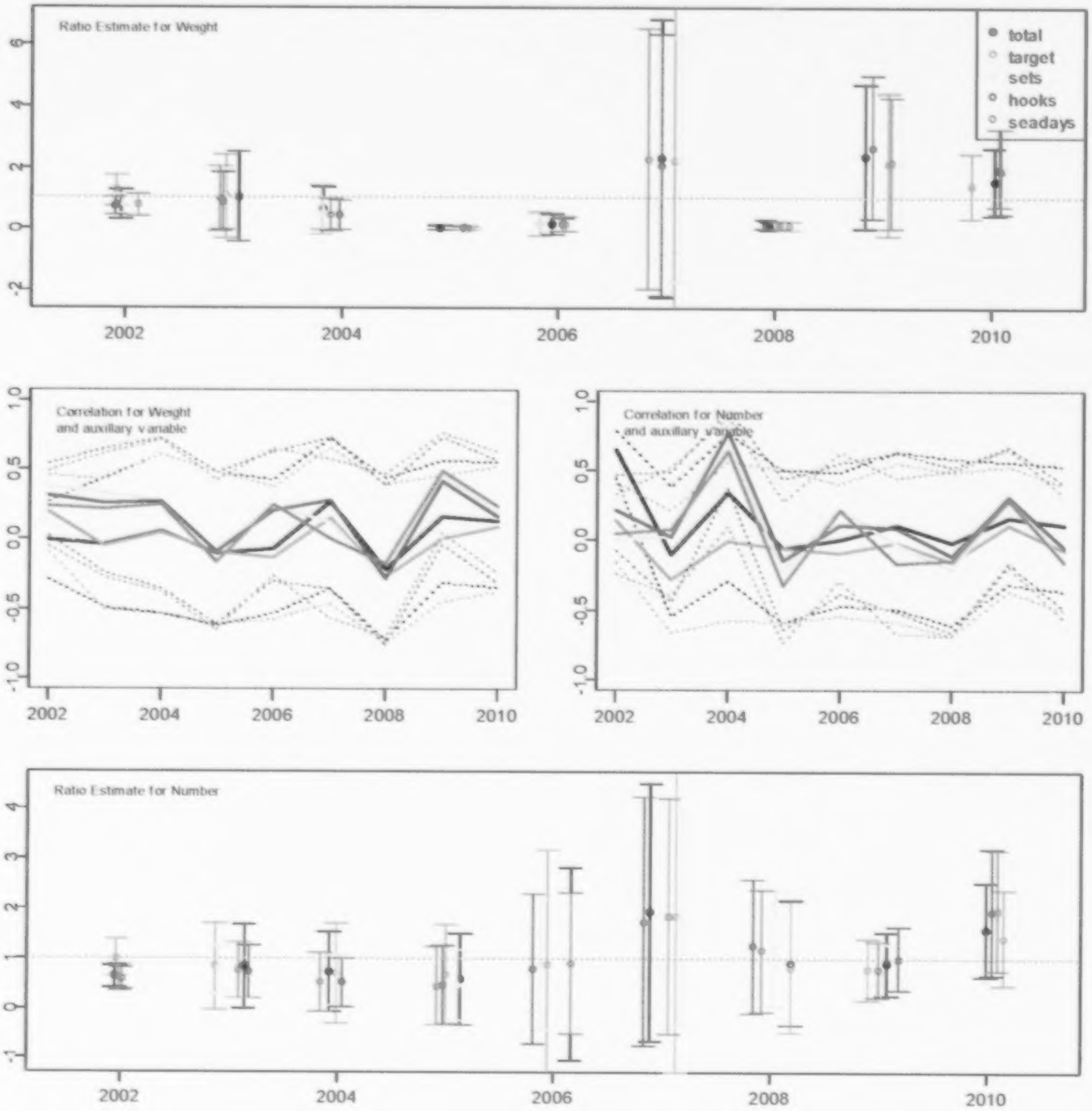


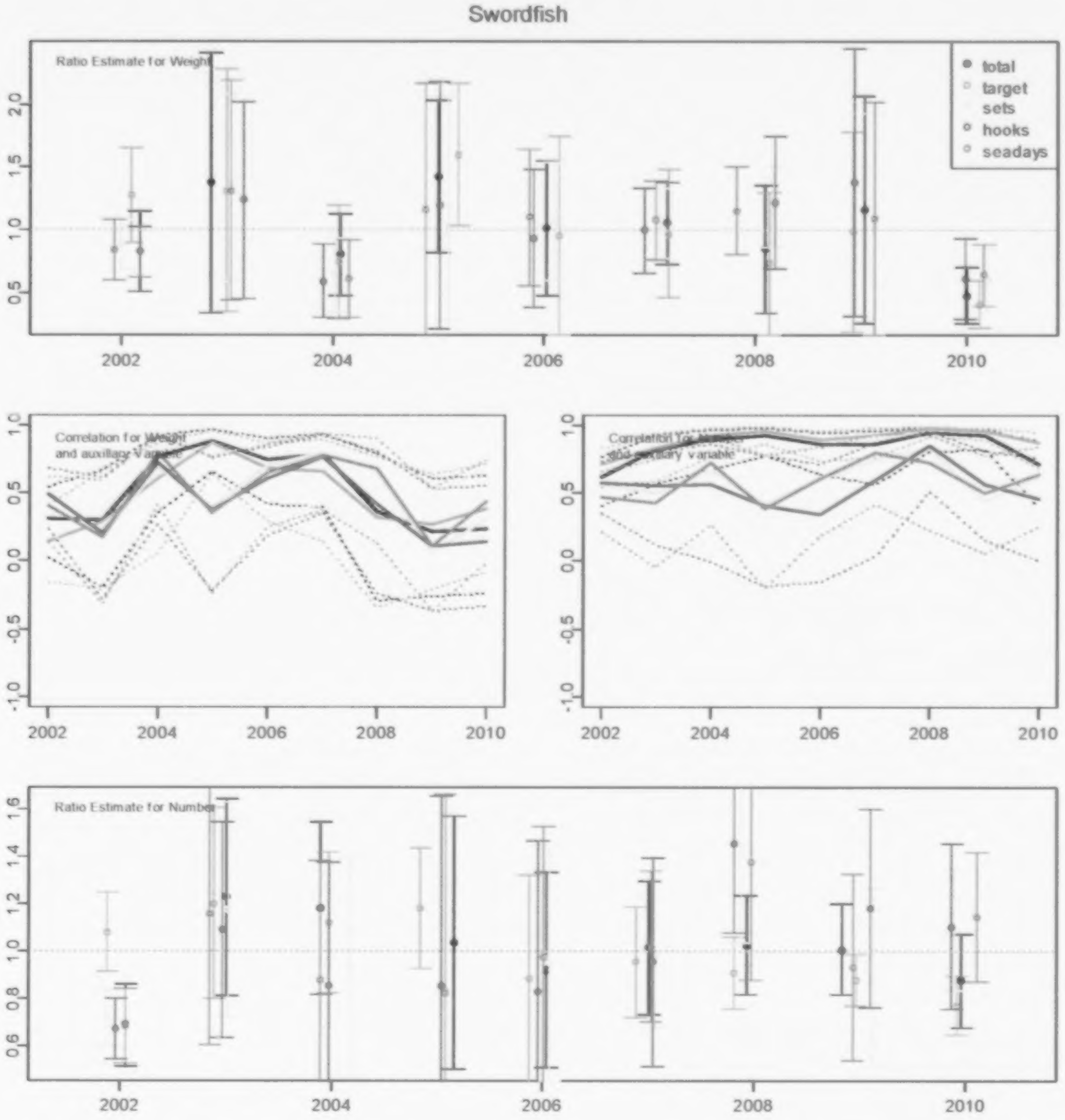
Figure 31. The cumulative number of unique vessels in the pelagic longline fishery (black) compared with the cumulative number of unique vessels observed (red) and the ratio (blue dotted).


Leatherback turtle

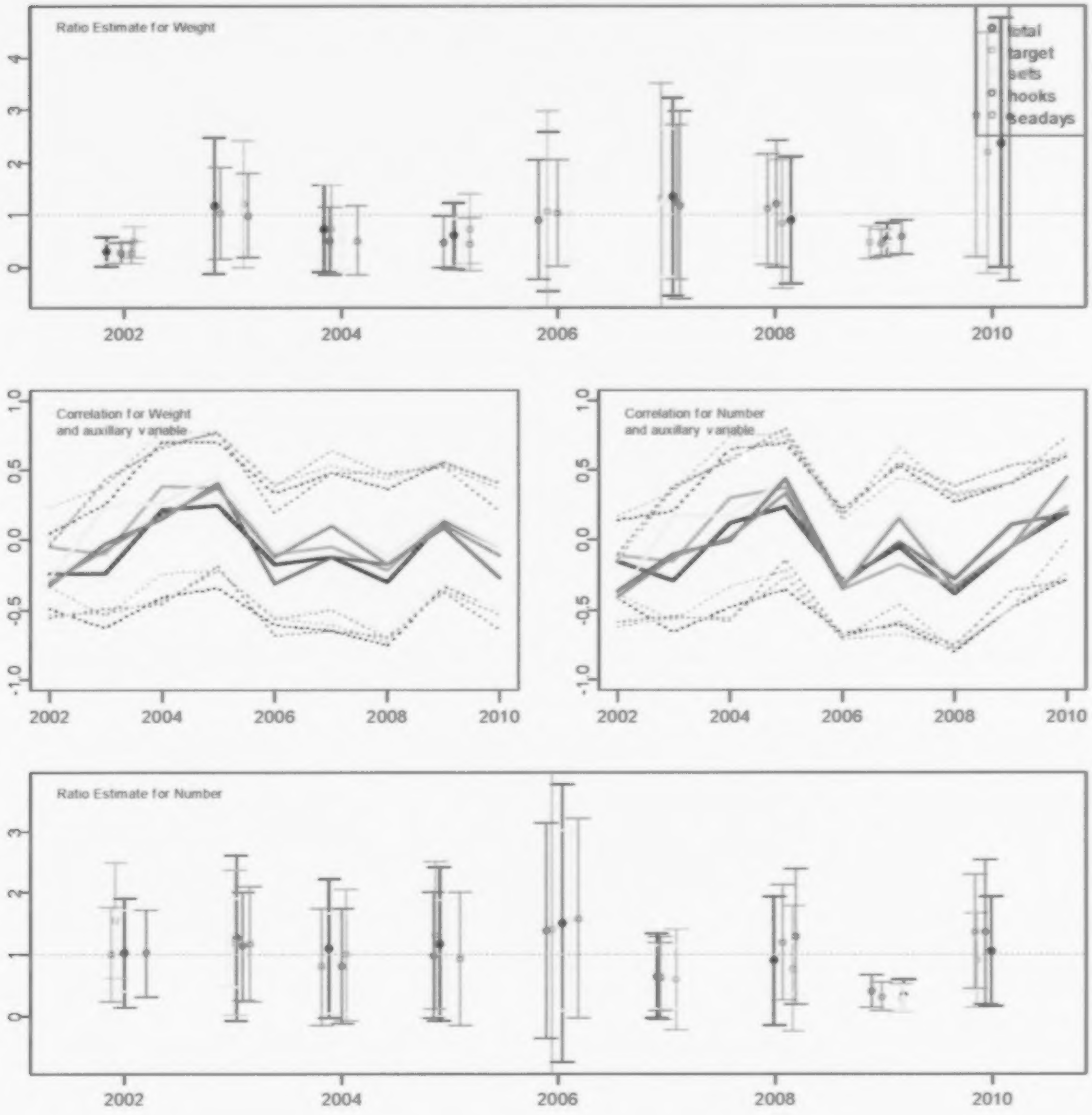

Loggerhead turtle
Ratio Estimate for Weight
total
target
sets
hooks
seadays
-1
0
1
2
3
4
5
2002
2004
2006
2008
2010
Correlation for Weight and auxillary variable
Correlation for Number and auxillary variable
-1.0
-0.5
0.0
0.5
1.0
Ratio Estimate for Number
6

Bluefin tuna

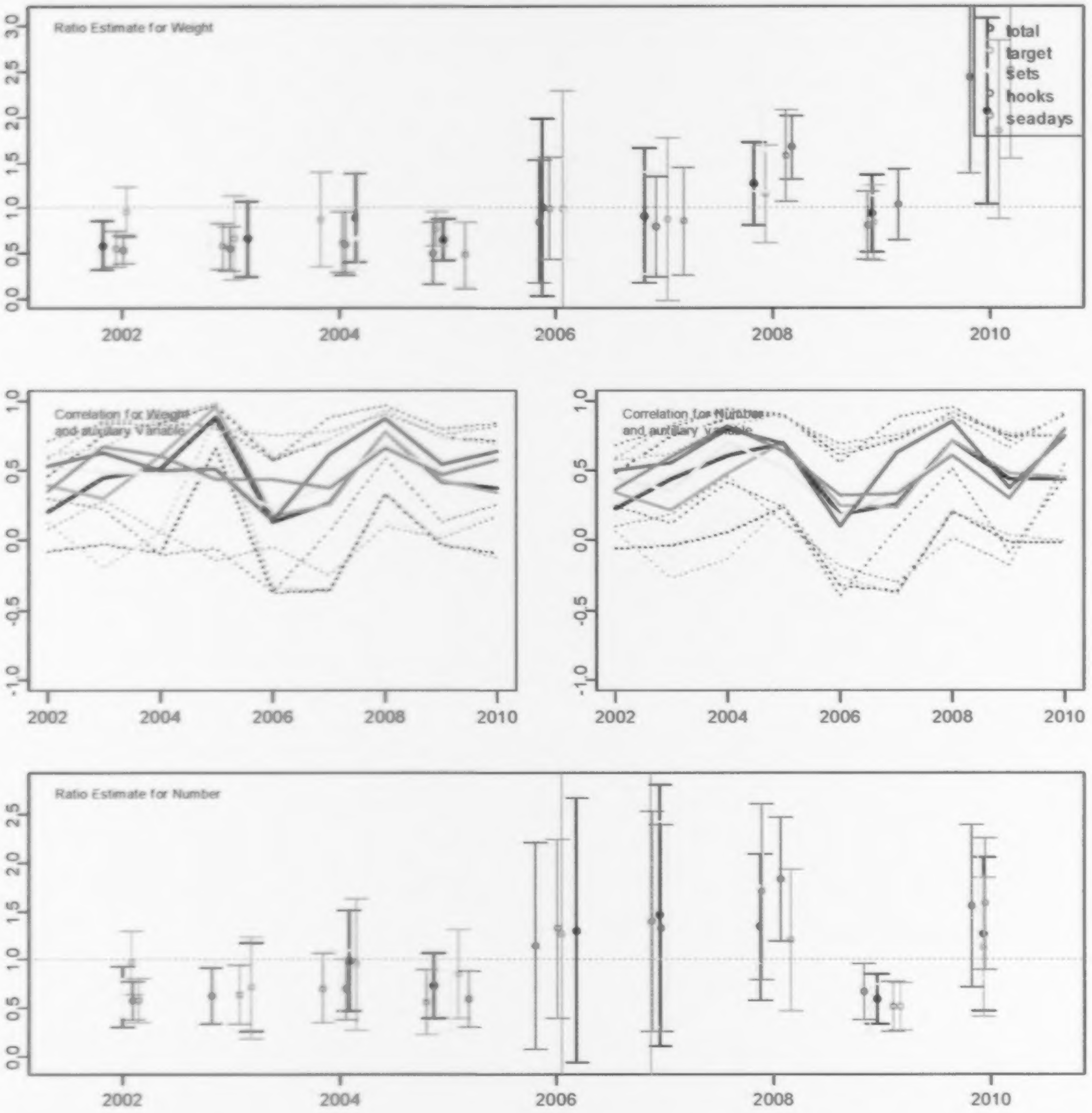



Swordfish
Ratio Estimate for Weight
total
target
sets
hooks
seadays
0.5
1.0
1.5
2.0
2002
2004
2006
2008
2010
Correlation for Weight and auxillary Variable
Correlation for Number and auxillary variable
-1.0
-0.5
0.0
0.5
1.0
Ratio Estimate for Number
0.6
0.8
1.0
1.2
1.4
1.6

Porbeagle shark



Blue shark


Ratio Estimate for Weight
total
target
sets
hooks
seadays
0.0
0.5
1.0
1.5
2.0
2.5
3.0
2002
2004
2006
2008
2010
Correlation for Weight and auxiliary Variable
Correlation for Number and auxiliary Variable
-1.0
-0.5
0.0
0.5
1.0
Ratio Estimate for Number

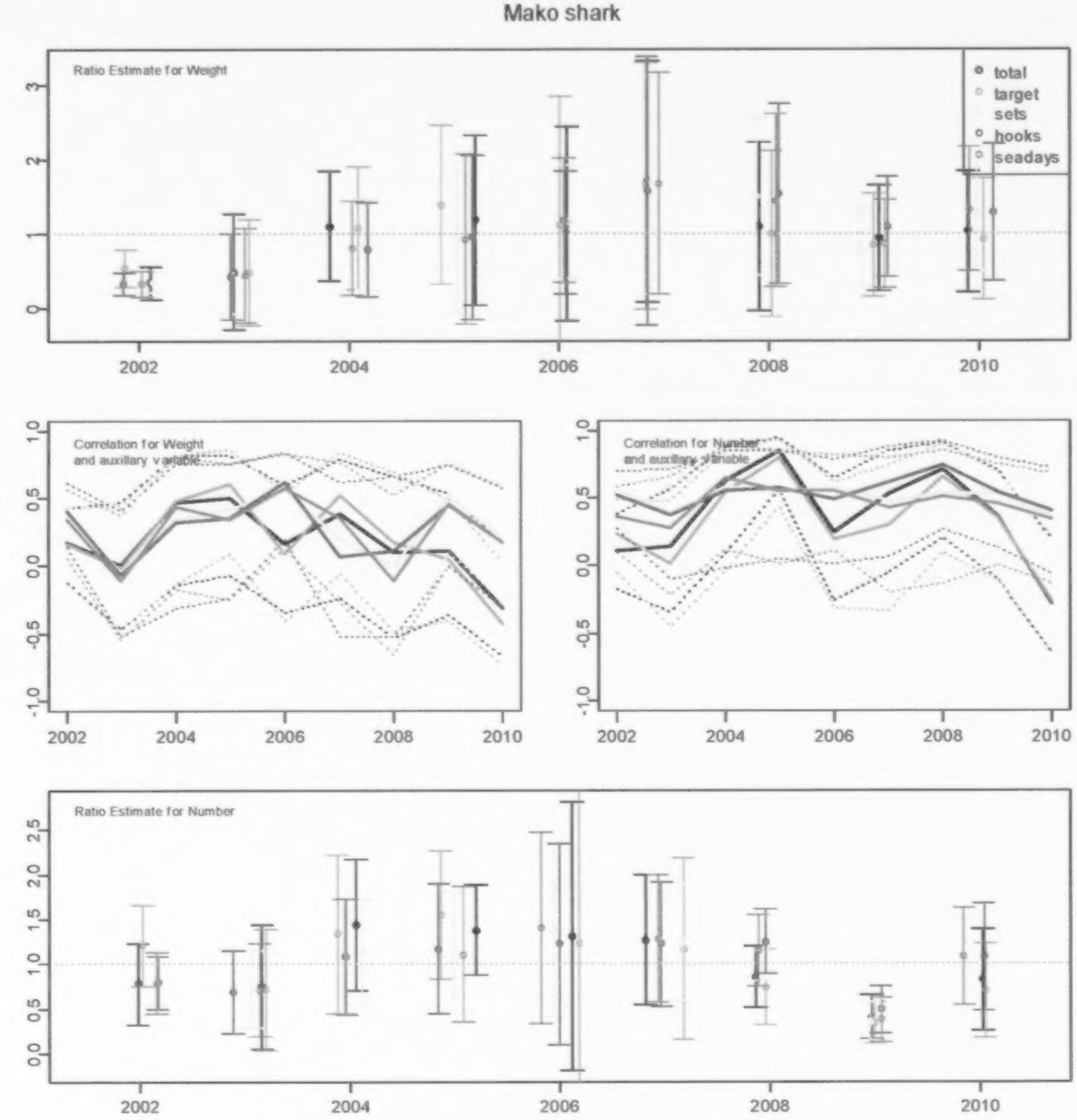
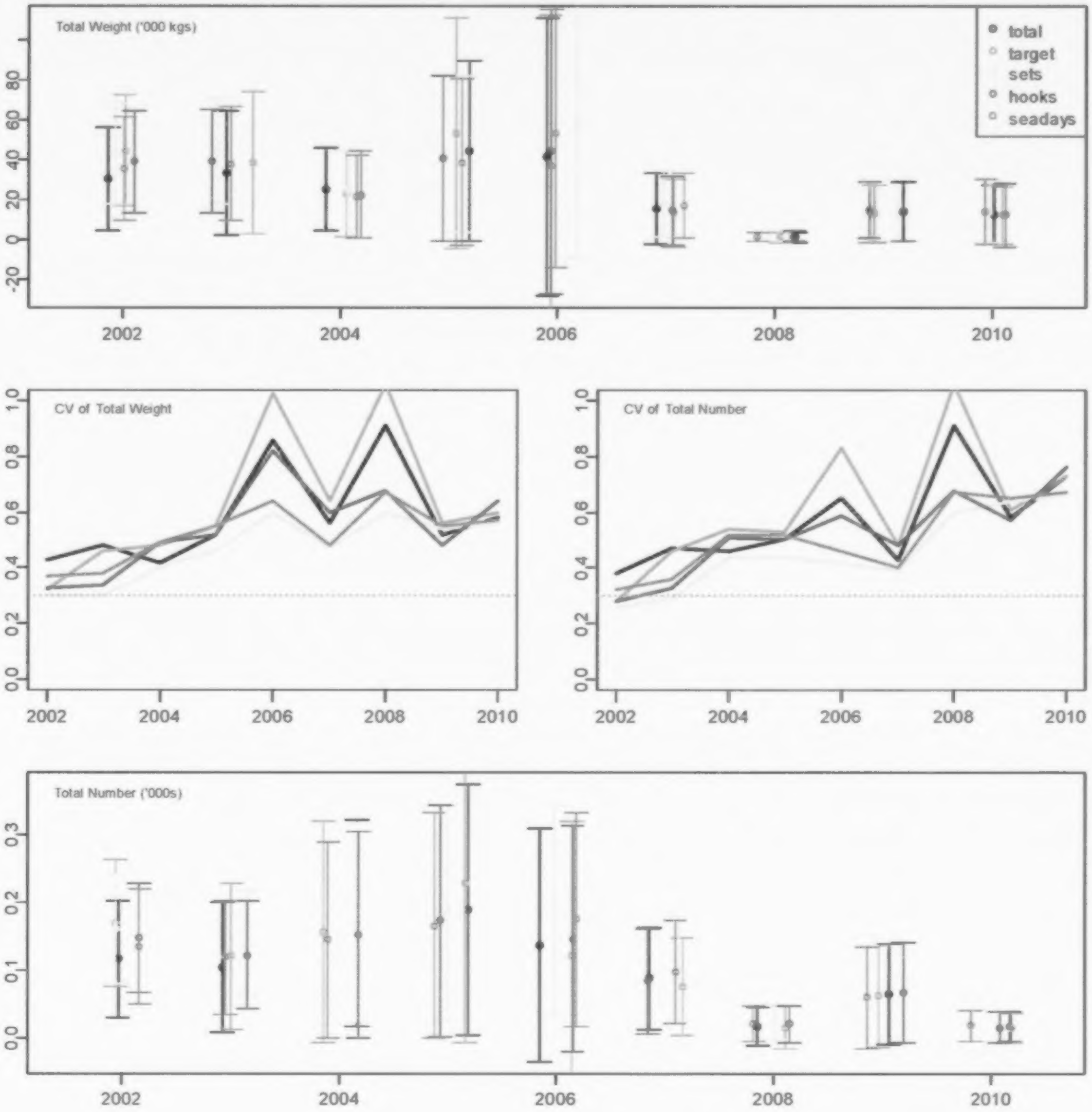
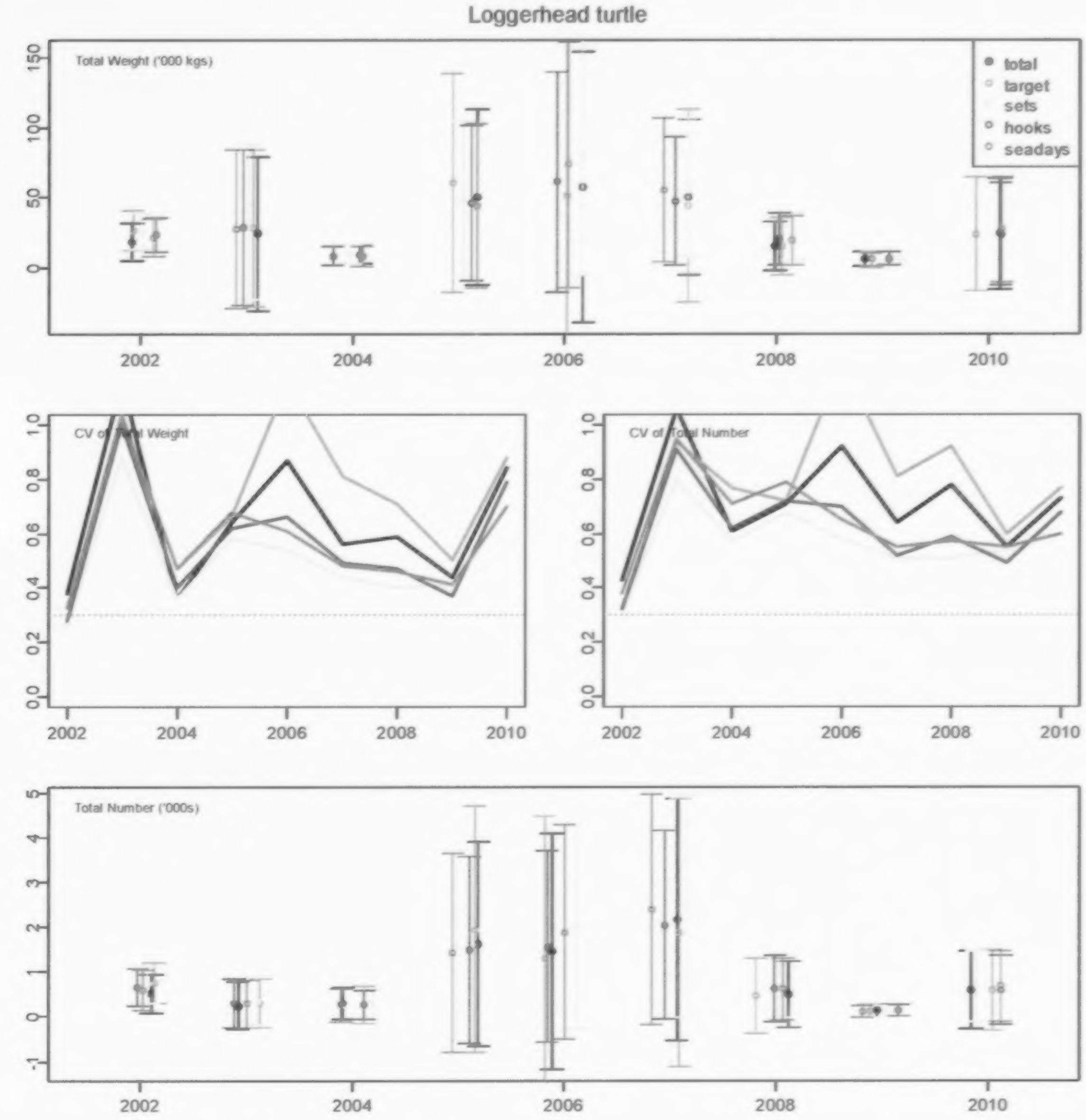
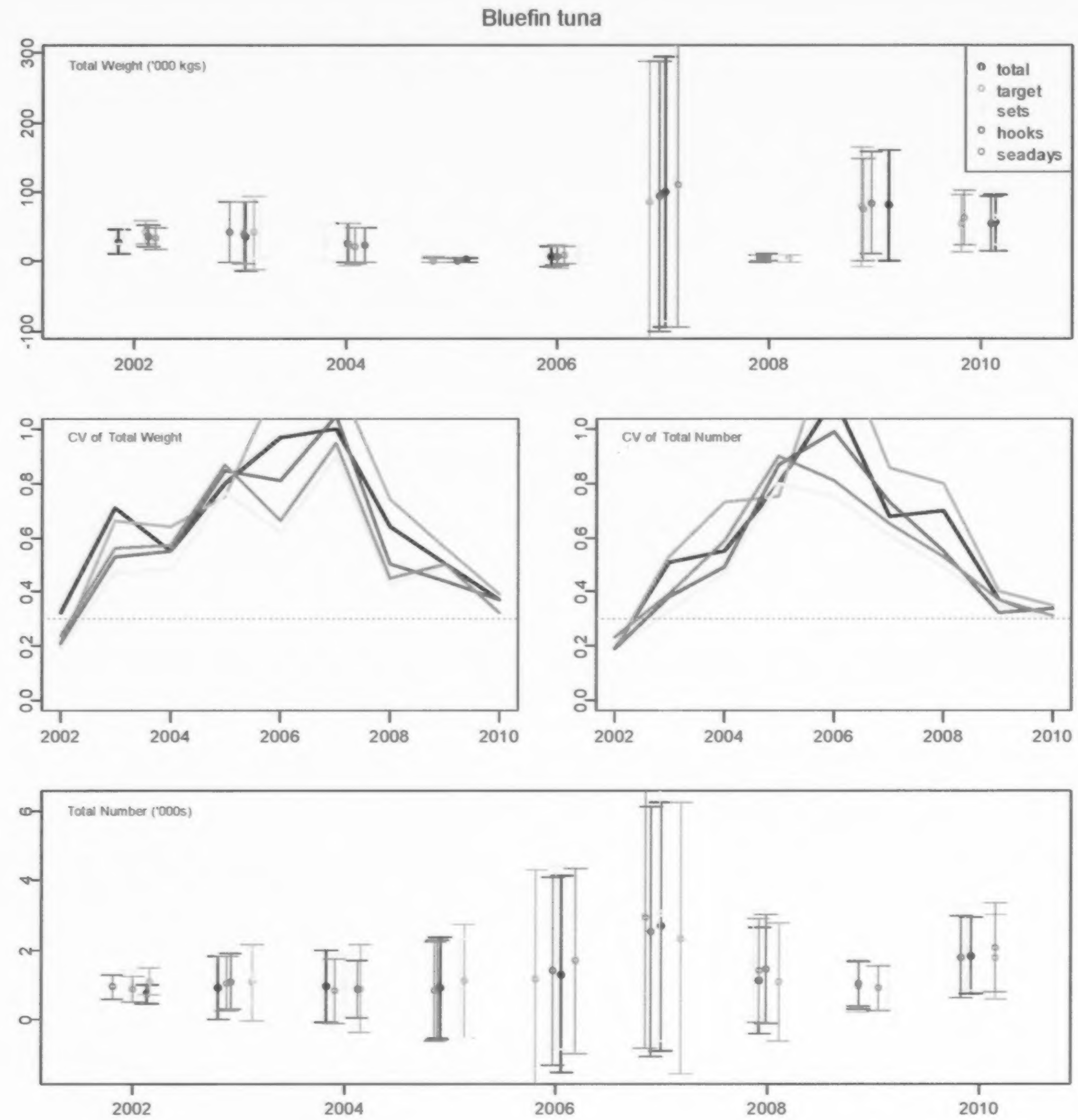


Figure 32. The ratio of the discard variables (weight and number) to auxiliary variables (weight of the catch (total), weight of swordfish kept (target), number of hooks, number of sets and number of sea days) and 95% confidence interval is estimated for each of seven species (loggerhead turtle: 9436, leatherback turtle: 9435, bluefin tuna: 71, swordfish: 72, blue shark: 231, porbeagle shark: 230 and short fin mako shark: 238) for 2002 to 2010. The correlation between the auxiliary variables and the discard weight and number are shown with their 95% confidence interval. The sample unit was trips and estimates are divided by the series average



Leatherback turtle


Loggerhead turtle
Total Weight ('000 kgs)
total
target
sets
hooks
seadays
150
100
50
0
2002
2004
2006
2008
2010
CV of Total Weight
CV of Total Number
0.0
0.2
0.4
0.6
0.8
1.0
Total Number ('000s)
5
4
3
2
1
0
-1



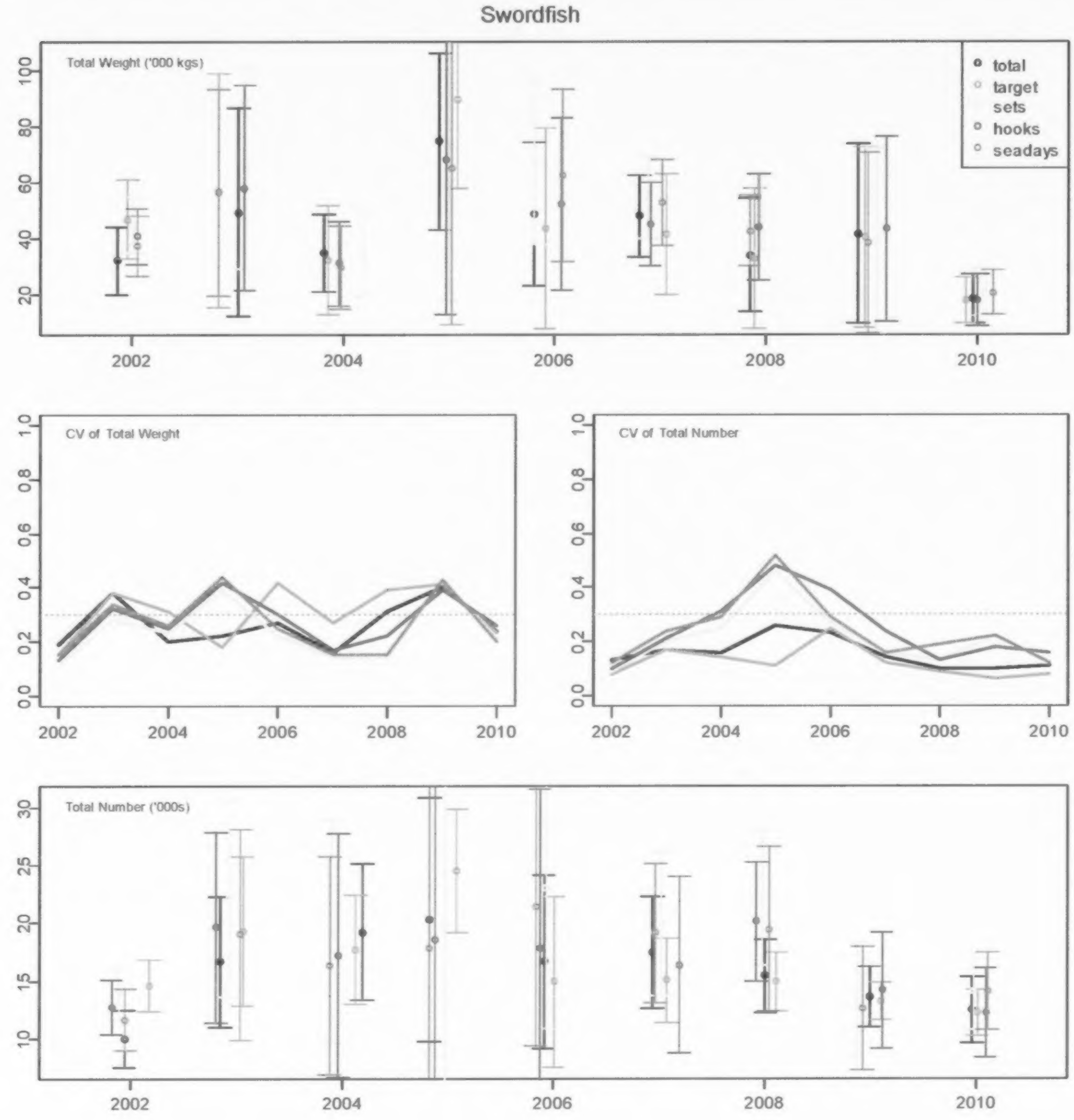
Bluefin tuna

Total Weight ('000 kgs)

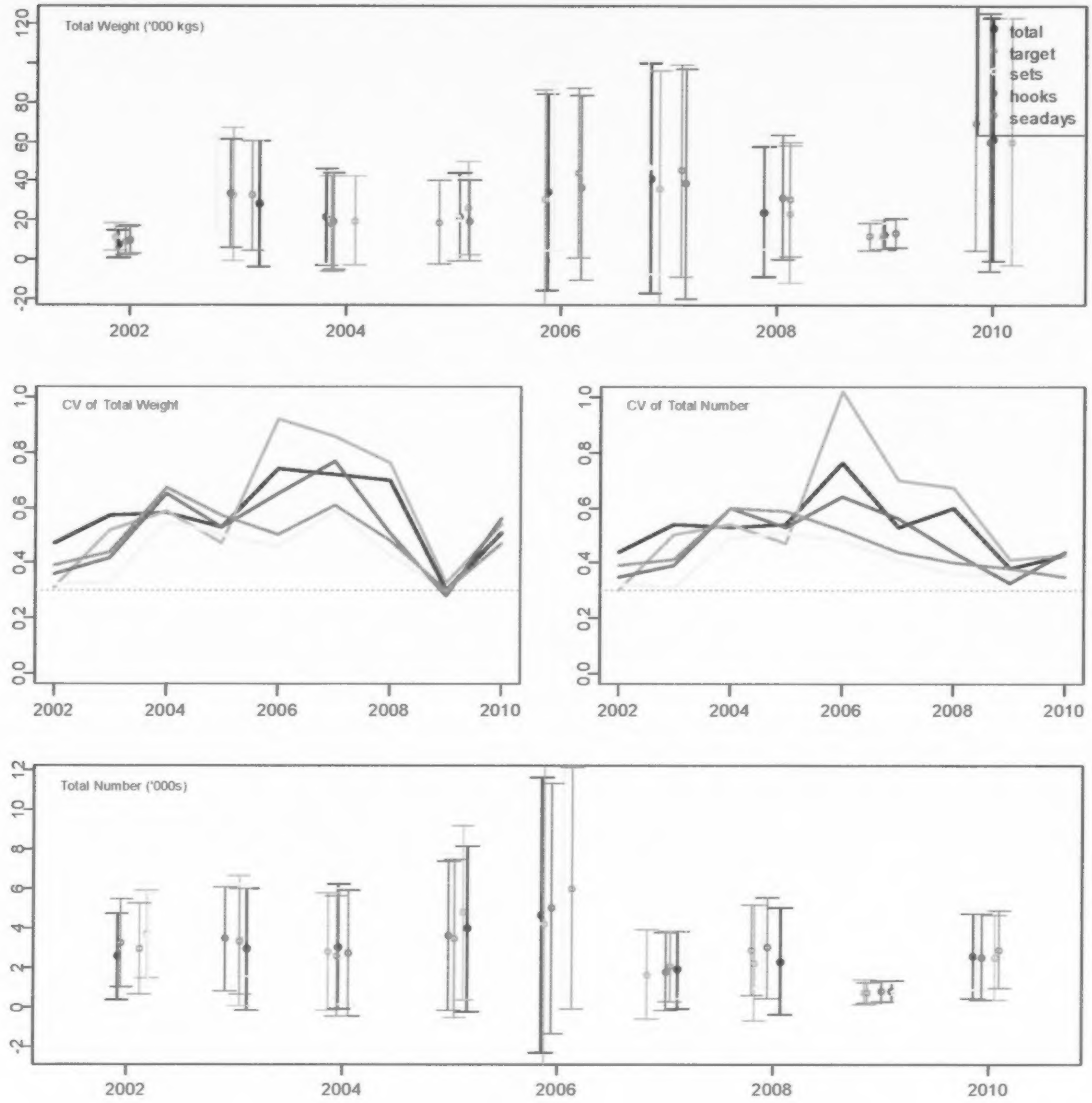
CV of Total Weight

CV of Total Number

Total Number ('000s)


Swordfish
Total Weight ('000 kgs)
total
target
sets
hooks
seadays
20
40
60
80
100
2002
2004
2006
2008
2010
CV of Total Weight
CV of Total Number
0.0
0.2
0.4
0.6
0.8
1.0
Total Number ('000s)
10
15
20
25
30

Porbeagle shark

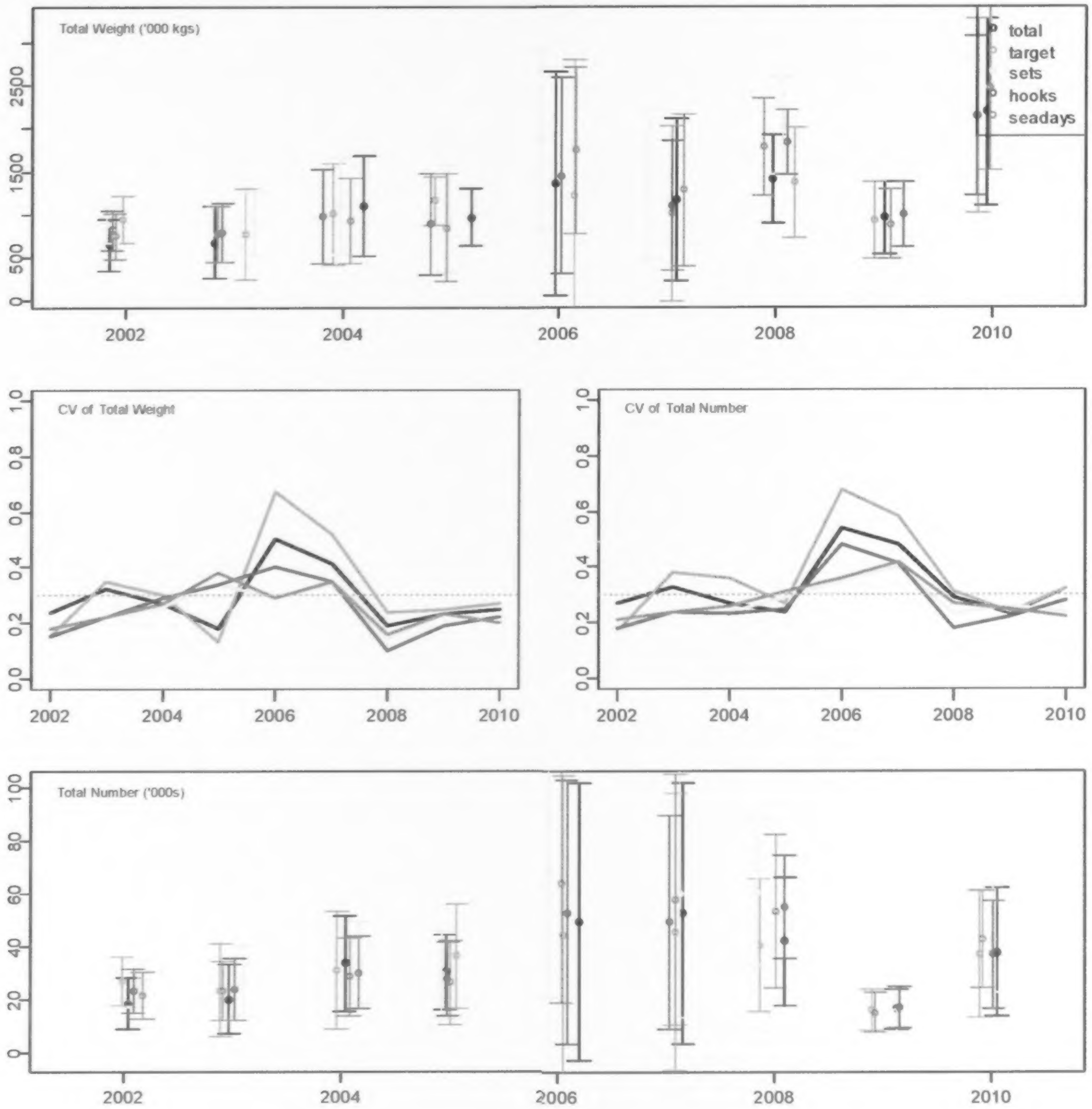

Total Weight ('000 kgs)

CV of Total Weight

CV of Total Number

Total Number ('000s)

Blue shark


Total Weight ('000 kgs)
0
500
1500
2500
2002
2004
2006
2008
2010
total
target
sets
hooks
seadays
CV of Total Weight
CV of Total Number
0.0
0.2
0.4
0.6
0.8
1.0
Total Number ('000s)
0
20
40
60
80
100

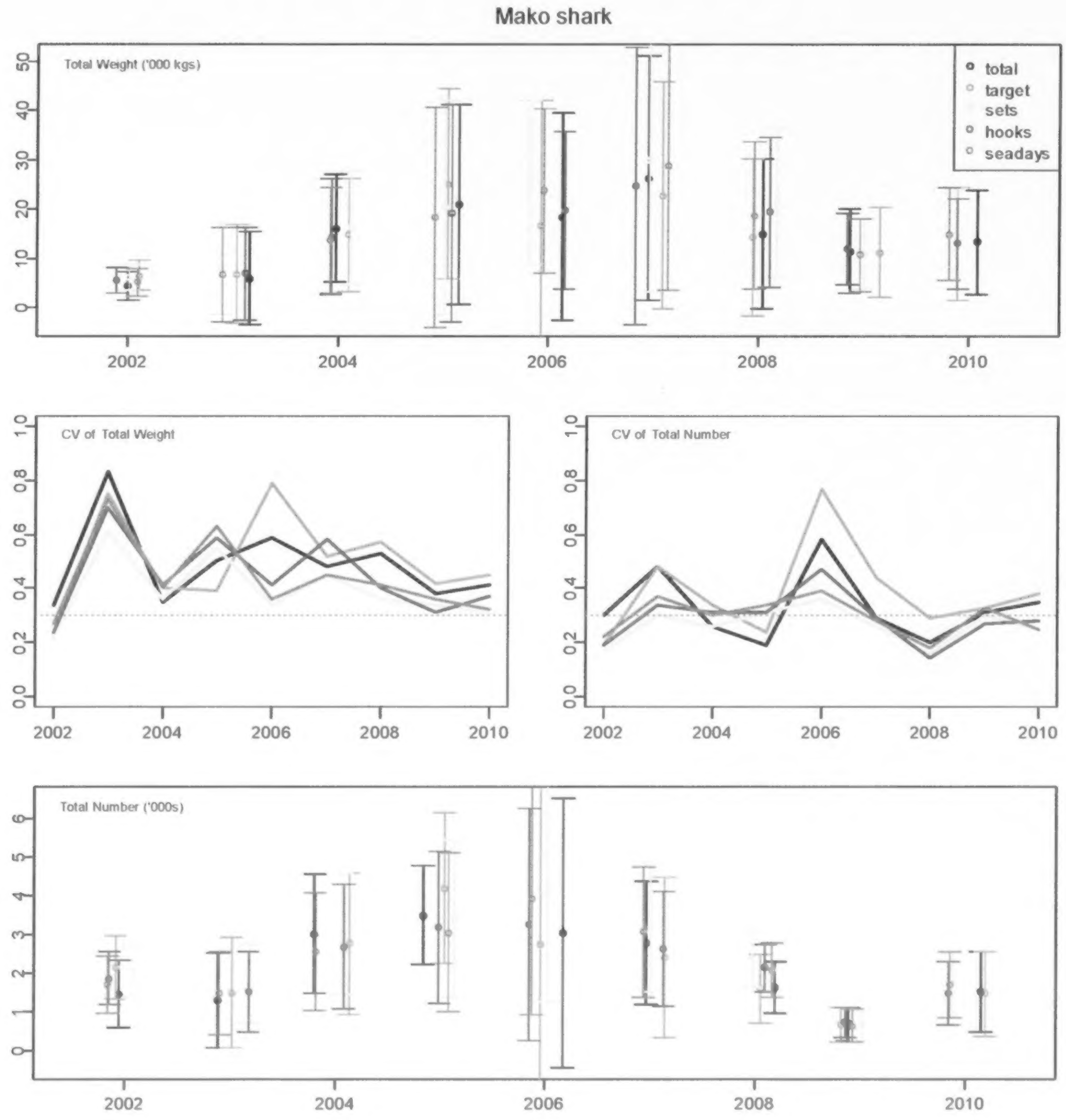
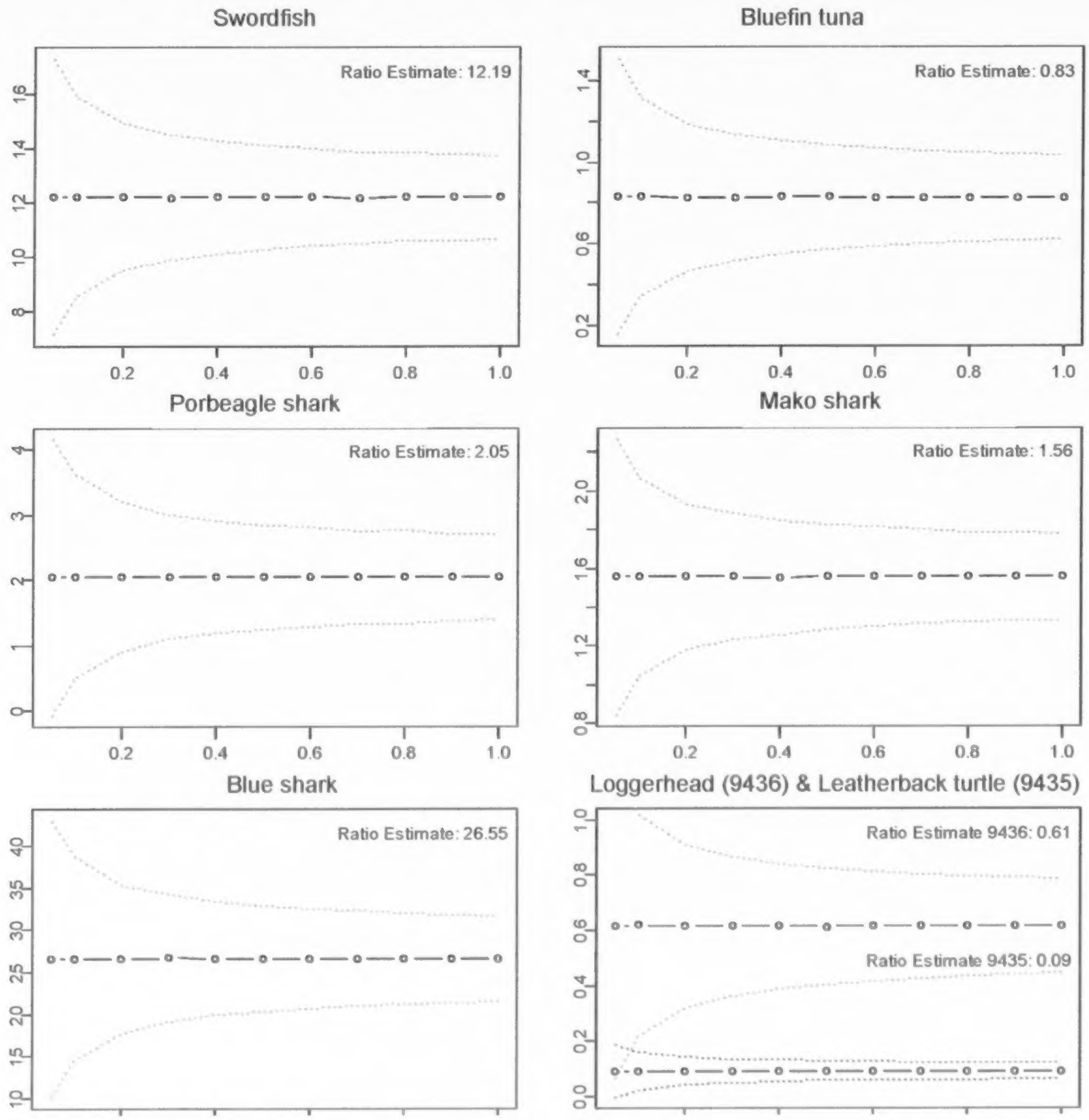


Figure 33. The estimate of the population total (discard weight and number) based on auxiliary variables (weight of the catch (total), weight of swordfish kept (target), number of hooks, number of sets and number of sea days) with 95% confidence interval for each of seven species (loggerhead turtle: 9436, leatherback turtle: 9435, bluefin tuna: 71, swordfish: 72, blue shark: 231, porbeagle shark: 230 and short fin mako shark: 238) encountered by the pelagic longline. The CV for the estimates of the population totals is shown. The sample unit was trips.



Swordfish

Bluefin tuna

Porbeagle shark

Mako shark

Blue shark

Loggerhead (9436) & Leatherback turtle (9435)

Figure 34. Monte Carlo simulation based estimates of the mean number of discards in the sample for seven species using the ISDB data spanning 2002 to 2010. The simulation for each species is based on 10,000 simulations of 1000 fishing sets.

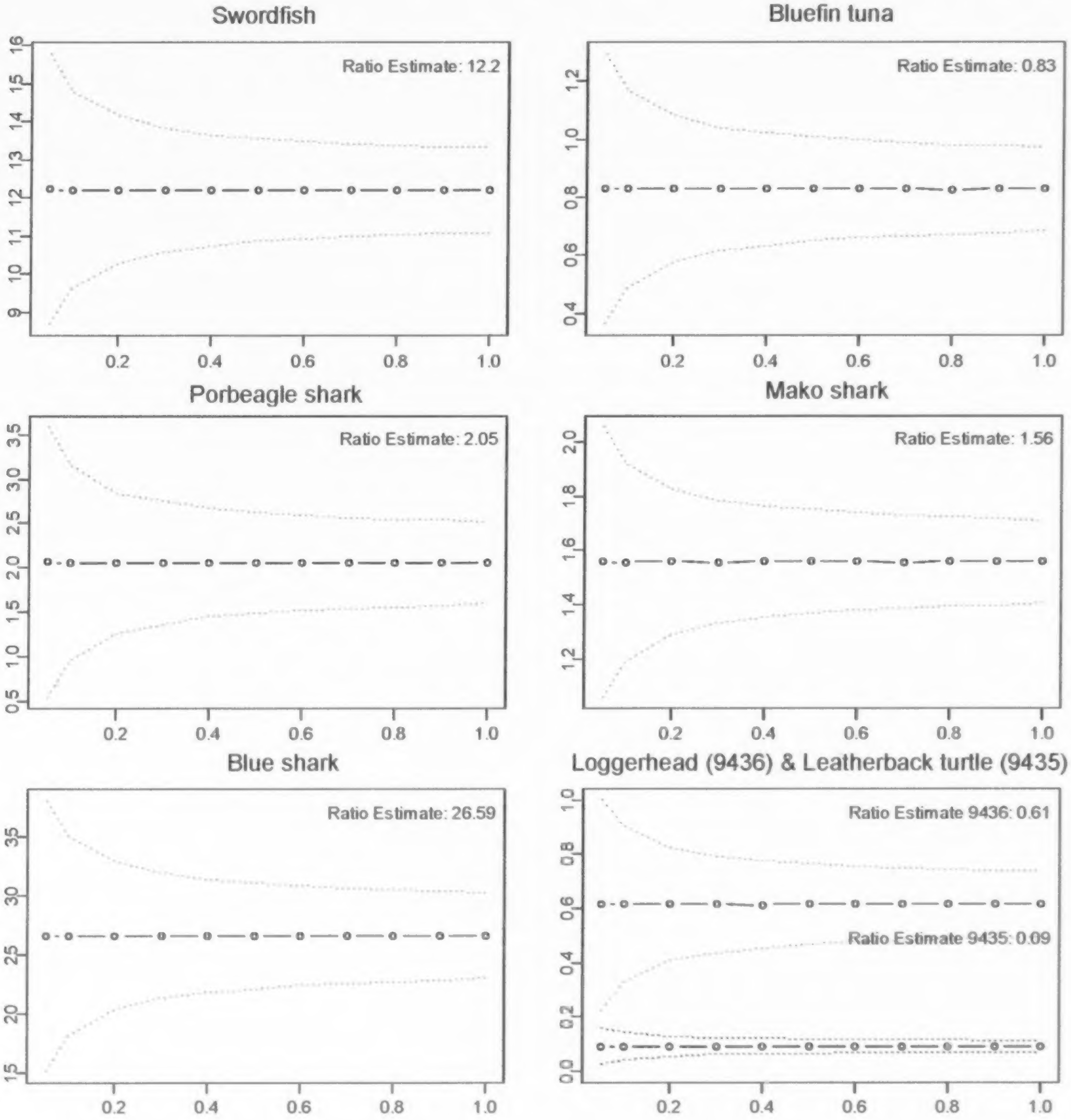


Figure 35. Monte Carlo simulation based estimates of the mean number of discards in the sample for seven species using the ISDB data spanning 2002 to 2010. The simulation for each species is based on 10,000 simulations of 2000 fishing sets.

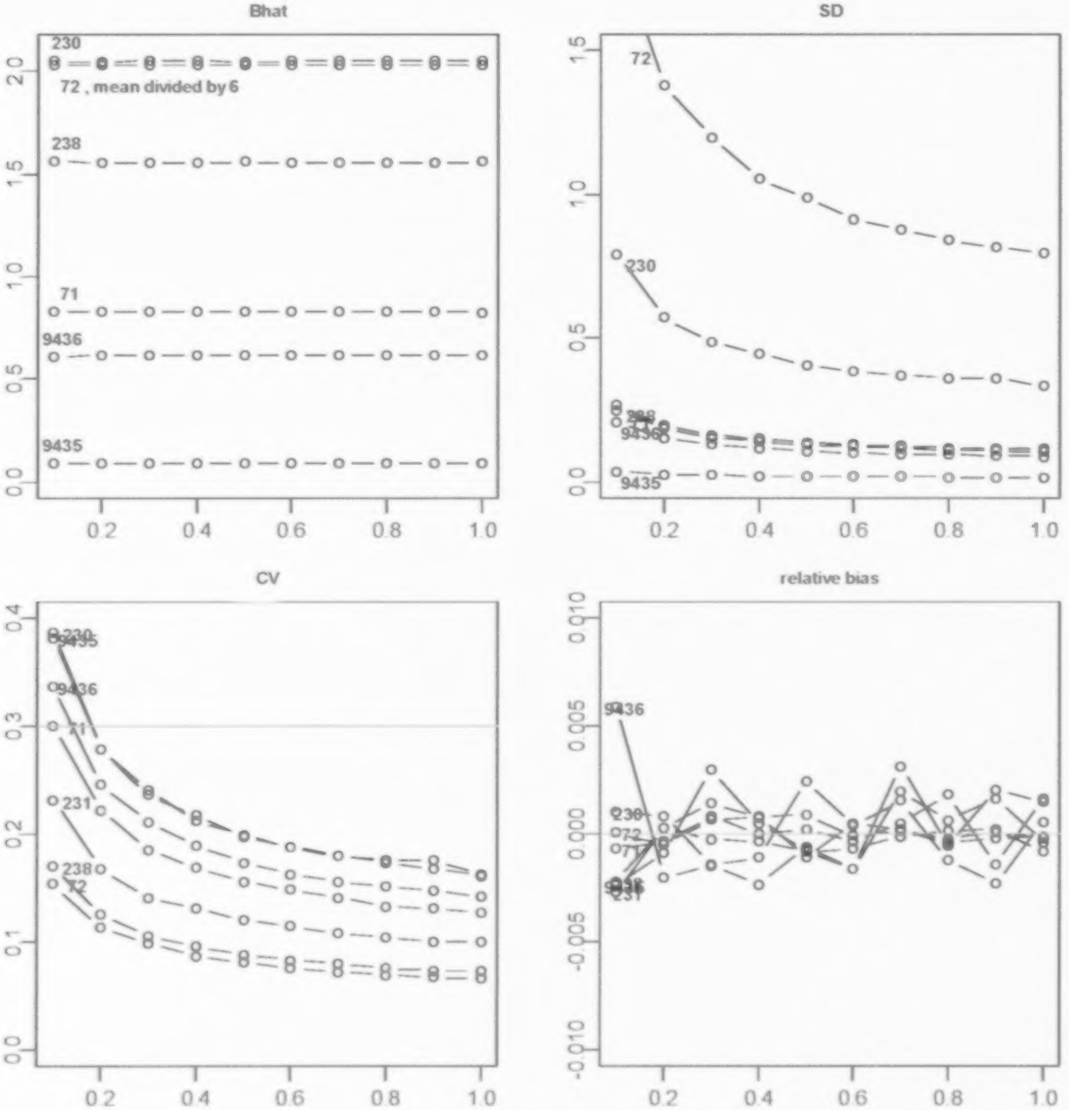


Figure 36. Monte Carlo simulation based estimates of the mean number of discards in the sample with its standard deviation, CV and relative bias for seven species using the ISDB data spanning 2002 to 2010. The simulation for each species is based on 10,000 simulations of 1000 fishing sets.

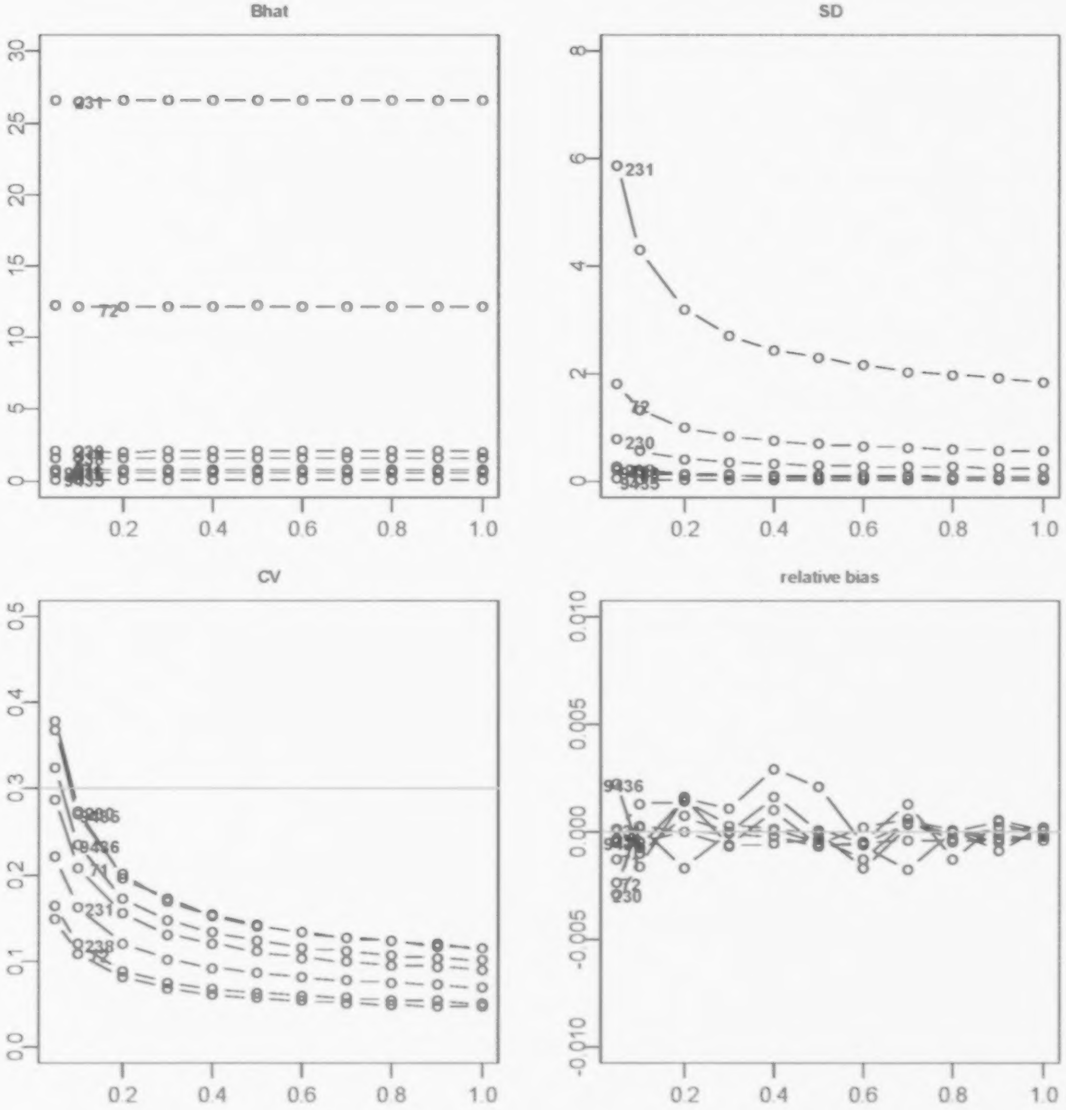


Figure 38. Monte Carlo simulation based estimates of the mean number of discards in the sample with its standard deviation, CV and relative bias for seven species using the ISDB data spanning 2002 to 2010. The simulation for each species is based on 10,000 simulations of 2000 fishing sets.

APPENDIX I

A SUMMARY OF THE STANDARDIZED BYCATCH REPORTING METHODOLOGY (SBRM)

Background

The SBRM:

- Describes a method of allocating observers to 40 fisheries (defined by gear type and mesh size) and encompasses 60 species. It is meant to simultaneously optimize observer coverage of the fleets and species, as well as maximize data usefulness and produce reasonable bycatch estimates.
- Estimates bycatch ratios, precision and accuracy calculations for individual and combinations of species (e.g., all species caught using large mesh), and includes both marine mammals and sea birds.
- Uses round weight of kept catch and discard for most animals (US equivalent of log sheets), and numbers of individuals for marine mammals and sea birds. For the sampling units, the SBRM relies on days absent and trips.
- Employs useful filters to remove unlikely combinations of species and gears (e.g., blue shark caught in a lobster pot).

Specifics

The SBRM:

- Used a design-based approach (versus a model-based).
- Looked at three ratio estimators:
  - i. total weight of species discarded to total weight of species kept.
  - ii. total weight of species discarded to days at sea .
  - iii. total weight of species discarded per trip.
- Looked at three methods of estimation:
  - i. separate ratio method.
  - ii. combined ratio method.
  - iii. simple expansion method.
- Stratified data by gear, access area, trip category, geographical region, mesh size and calendar quarter. The strata were nested, not factorial.
- Set a CV goal of 0.3 for its fisheries and estimated the number of trips or sea days required to attain that level of precision.
- For longline, found strong correlation among estimators and low levels of uncertainty for the three methods, indicating low variability and strong association.

Differences and Application of the SBRM to the Canadian PLL fishery

The SBRM:

- Has a complex structure incorporating many fisheries and species. As we are looking at one fishery with seven relevant species, such complexity is unnecessary. In addition, the SBRM incorporates two different sampling protocols for observers (complete and incomplete) for given species and fisheries (e.g., mammals caught in gill nets).

- Did not use VMS data, as the US VMS fishery coverage is incomplete. Canadian PLL fishery has 100% VMS coverage, which could be incorporated into the analysis.
- The SBRM takes measures to impute data for fisheries that have no observer coverage; this should not be applicable to the Canadian PLL.
- The SBRM did not consider individual stocks, only geographical areas, which may be possible for Canadian stocks.
- The federal US observer program has a single major source of funding; allowing them more freedom to allocate observers between fisheries once the bare minimum for select fisheries has been met. The Maritime structure is not open to shifting observer sea days between fisheries.
- Although both Canadian and US logbook databases have caveats, the US has the option of comparing catch data to data from fisheries buyers (US buyers have a mandatory obligation to report 100% of their purchases).

Criticisms of the SBRM (Murdoch, 2007)

The SBRM:

- Does not acknowledge flaws of observer data (e.g., subjectivity) and does not quantify bias of neither observer nor catch data; ignores findings that observer trips were not representative of fishery activity.
- Chose the ratio method, despite other methods performing better in statistical tests. In addition, the chosen method violates key assumptions identified by authors as being critical.
- Did not run simulated data checks to see if output estimates were reasonable
- Very little assurance of bycatch estimate precision and accuracy.